APPENDIX A

SUPPLEMENTARY BLAST DATA [redacted]

[redacted] This appendix consists of two sections. Section I is a collection of equations and data useful in the study of shock waves. Section II contains a description of certain shock wave properties in a way that is intended to convey an understanding of these topics. None of the information in this appendix is required to solve the problems in Chapter 2 concerning blast phenomena or the blast related problems in the chapters of Part II of this manual. This appendix provides supplementary information, useful for solving special problems or for developing a better physical understanding of the phenomena described in Chapter 2.

[redacted] The shock wave equations presented in this appendix are those that are most likely to be encountered in the study of air blast phenomena, and the concepts that are discussed are those that are most likely to be troublesome to the person who is studying shock wave theory for the first time.

[redacted] This appendix presupposes a reasonable familiarity with the laws of mechanics and some understanding of how these laws apply to energy and momentum exchange in gases in motion.

SECTION I

[redacted] MATHEMATICAL DESCRIPTION OF THE SHOCK FRONT [redacted]

[redacted] Most mathematical descriptions of shock wave phenomena are focused on the shock front itself since shock front conditions are fairly easy to treat mathematically, but the characteristics of the waveforms that follow the front are not. This limitation is not serious for many types of calculations, because the strength of the shock front is usually the best indicator of the severity of the entire shock wave.

[redacted] In the absence of direct, simple mathematical techniques, analysis of the shock waveform usually depends on empirical data such as the predetermined shock waveforms shown in paragraph 2-12, Chapter 2. Numerical integration of shock wave problems on a computer provides an alternate method. The computer codes for blast waves from nuclear weapons incorporate the details of weapon configuration, radiation transport, and hydrodynamics; these codes are complex and their characteristics will not be discussed here.

A-1 The Rankine-Hugoniot Equations [redacted]

[redacted] A set of three equations governing shock front behavior may be derived from the laws of mechanics. These equations (or any set of three independent equations derived from them) are called the Rankine-Hugoniot equations. They do not completely specify shock front behavior; a fourth equation, the equation of state of the material, is necessary to specify the complete behavior of the shock front. However, these equations have the advantage of being valid for all conditions under which a shock front can occur. They apply equally well to shock waves in solids and in gases.

[redacted] The equations given below outline the conventional derivation of the Rankine-Hugoniot equations. The same set of equations are derived in Section II in a manner that requires less algebra but more physical reasoning. The three conservation equations that lead to the Rankine-Hugoniot equations involve the so-called jump conditions across a shock front. The parameters involved are illustrated in Figure A-1.

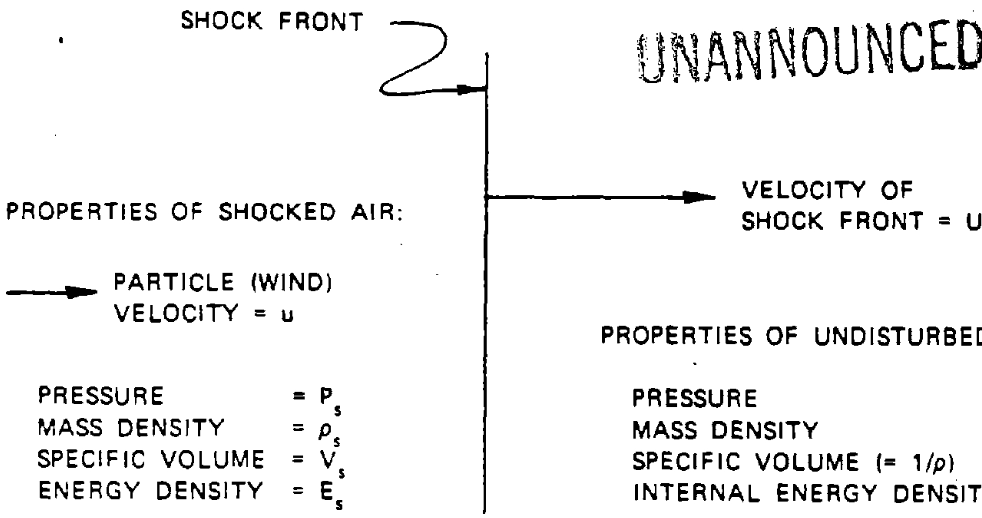

Figure A-1. (U) Change in Air Properties Across a Shock Front [redacted]

[redacted] An equation for the conservation of mass states that the mass of air per unit time overtaken by a unit area of the shock front is equal to the mass of air per unit area per unit time added behind the shock front.

$$\rho U = \rho_s(U - u),$$

where ρ is the ambient air density, U is the shock velocity, ρ_s is the density of the air behind the shock front, and u is the peak velocity of the air behind the shock front.

[redacted] Newton's second law states that force is equal to the rate of change of momentum. The force per unit area acting to accelerate the air entering the shock front is the overpressure, $\Delta p = P_s - P$, where P_s is the absolute pressure behind the shock front and P is the ambient pressure. The mass per unit time that enters a unit area of the shock front is ρU. The change of velocity of the air is u. Thus,

$$\Delta p = P_s - P = \rho U u.$$

[redacted] Conservation of energy requires that the work done while the shock front moves through a unit mass of air, $P_s\ (V - V_s)$, must equal the kinetic energy imparted to the unit mass of air, $u^2/2$, plus the change in internal energy, $E_s - E$, where the various symbols are defined in Figure A-1. Thus,

$$P_s \Delta V = (u^2/2) + (E_s - E),$$

or

$$P_s(V - V_s) = (u^2/2) + (E_s - E).$$

Using the relations $V = 1/\rho$ and $V_s = 1/\rho_s$, a simultaneous solution of these three equations leads to the Rankine-Hugoniot equations in their usual form:

$$E_s - E = \frac{1}{2}(P_s + P)(V - V_s),$$

$$u = \left((P_s - P)(V - V_s)\right)^{1/2},$$

$$U = V\left(\frac{P_s - P}{V - V_s}\right)^{1/2}.$$

A-2 Equation of State of an Ideal Gas [redacted]

[redacted] A gas that is heated at constant volume does not do external work; therefore, all of the thermal energy added to the gas is converted to internal energy. This amount of energy is

$$\Delta E = C_V \Delta T$$

where ΔE is the change in internal energy per unit mass, C_V is the specific heat of the gas at constant volume, and ΔT is the temperature change. By definition, the specific heats of an ideal gas are constant; and the internal energy per unit mass is

$$E = C_V T,$$

where T is absolute temperature.

[redacted] Using the thermodynamic identities PV [redacted], and $C_P - C_V = R$ (where C_P is specific heat at constant pressure, and R is the universal gas constant) the following equation follows:

$$E = \frac{C_V PV}{C_P - C_V} = \frac{PV}{\gamma - 1}$$

where

$$\gamma = \frac{C_P}{C_V}.$$

Eliminating the variables E_s and E makes it possible to use the Rankine-Hugoniot equations to determine the conditions across a shock front in an ideal gas uniquely.

[redacted] The significance of the quantity γ as it appears in the shock wave equations deserves some explanation. In thermodynamics, γ appears most frequently in equations that involve isentropic compression. For example, γ appears in the equation for sound speed because sound wave pressure fluctuations are isentropic. The presence of γ in shock wave equations is sometimes incorrectly interpreted as implying a relationship between shock wave compression and isentropic compression; actually, γ is a convenient constant relating energy content of a gas to pressure and volume. This fact becomes important in paragraph A-6 where strong shock waves are discussed. Variations in the value of γ must then be considered, and the equations

$$\Delta E = C_V \Delta T, \text{ and}$$

$$E = C_V T$$

cannot hold simultaneously. Conveniently, γ is redefined, so the equation

$$\Delta E = C_V \Delta T$$

still may be used. The meaning of γ as a specific heat ratio is lost, and γ becomes simply a constant in the energy equation.

A-3 Shock Wave Equations for an Ideal Gas (U)

[redacted] From the relation for the speed of sound in ambient air,

$$c = (\gamma P/\rho)^{1/2}$$

and the equation for overpressure,

$$\Delta p = P_s - P$$

the set of shock wave equations shown in Table A-1 can be derived. The equations in the right hand column were obtained by assigning to γ the value 1.4, the value for air at moderate temperatures and pressures.

[redacted] These ideal gas equations apply to shock

Table A-1. [redacted] Shock Wave Equations for an Ideal Gas [redacted]

Equations in General Form:	Equations for $\gamma = 1.4$
Velocity of the Shock Front	
$U = c\left(1 + \frac{\gamma + 1}{2\gamma} \cdot \frac{\Delta p}{P}\right)^{1/2}$	$U = c\left(1 + \frac{6\Delta p}{7P}\right)^{1/2}$
Particle Velocity Behind the Shock Front	
$u = \frac{\Delta p}{\gamma P} \cdot \frac{c}{\left(1 + \frac{\gamma + 1}{2\gamma} \cdot \frac{\Delta p}{P}\right)^{1/2}}$	$u = \frac{5\Delta p}{7P} \cdot \frac{c}{(1 + 6\Delta p/7P)^{1/2}}$
Density Ratio Across the Shock Front	
$\frac{\rho_s}{\rho} = \frac{2\gamma + (\gamma + 1)\Delta p/P}{2\gamma + (\gamma - 1)\Delta p/P}$	$\frac{\rho_s}{\rho} = \frac{7 + 6\Delta p/P}{7 + \Delta p/P}$
Dynamic Pressure Behind the Shock Front	
by definition, $q = \frac{1}{2}\rho_s u^2$	
$q_s = \frac{(\Delta p)^2}{2\gamma P + (\gamma - 1)\Delta p}$	$q_s = \frac{5}{2} \cdot \frac{(\Delta p)^2}{7P + \Delta p}$
Temperature Behind the Shock Front	
$T_s = T\left(1 + \frac{\Delta p}{P}\right)\frac{2\gamma + (\gamma - 1)\Delta p/P}{2\gamma + (\gamma + 1)\Delta p/P}$	$T_s = T\left(1 + \frac{\Delta p}{P}\right)\frac{7 + \Delta p/P}{7 + 6\Delta p/P}$
Peak Reflected Overpressure at Normal Incidence	
$\Delta p_r = 2\Delta p + (\gamma + 1)q$	$\Delta p_r = 2\Delta p \frac{7 + 4\Delta p/P}{7 + \Delta p/P}$

[redacted] waves in air provided the shock strength. $\xi = (\Delta p + P)/P = P_s/P$, is not too large. Usually these equations are assumed to hold for shock strengths of about 10 (132 psi overpressure at sea level) or less; note that at high altitudes this limit corresponds to relatively low overpressures, e.g., about 25 psi at 40,000 ft. The equations for high pressure shock waves are given in paragraph A-6.

[redacted] As shown in Figure A-1, the subscript s denotes conditions behind the shock front; the absence of a subscript denotes ambient conditions (the subscript o is reserved for ambient conditions at sea level as in Chapter 2). The overpressure is $\Delta p = P_s - P$; c is the speed of sound in undisturbed air; and γ is the ratio of specific heats C_P/C_V. Other quantities are defined by subheadings in the table.

A-4 Units, Constants, and Conversion Factors [redacted]

[redacted] Since the most commonly used shock wave equations are written in terms of dimensionless ratios, the choice of units is purely a matter of convenience; therefore, there is an inclination to ignore the fact that certain equations must be handled more carefully. Examples of these equations are the Rankine-Hugoniot equations and the dynamic pressure equation. Three consistent sets of units in common use are shown in Table A-2. Conversion factors and sea level values of various parameters are given in the various units in Appendix B.

A-5 Equation of State of Air [redacted]

[redacted] As air is heated by the compression of strong shock waves, the specific heat ratio γ decreases. Therefore, the equation that gives γ in terms of the ratios of the specific heats, which is based on the assumption of a constant γ, is no longer valid. The means of avoiding this problem has already been stated in paragraph A-2: γ_s customarily is *redefined* as that number which gives the correct value for internal energy. Since γ appears frequently in shock wave equations to replace an energy term, the new definition is a convenient one. Note, however, that (except in undisturbed air, where the new and old definitions of γ agree) γ is no longer the specific heat ratio. Therefore, γ should not be used (for example) to calculate sound speed in strongly shocked air.

Table A-2. [redacted] English and Metric Systems of Units [redacted]

Unit	mks	cgs	English
length	meter	centimeter	foot
mass	kilogram	gram	pound
force	newton	dyne	slug
time	second	second	second
pressure	newtons/m^2	dynes/cm^2	pounds/ft^2
density	kg/m^3	g/cm^3	slugs/ft^3
velocity	m/sec	cm/sec	ft/sec
energy	joule	erg	ft-lb

[redacted] Figure A-2 shows the equation of state of air for altitudes up to 240,000 feet. The nearly vertical curves are the Hugoniot curves for air at the indicated altitudes. The Hugoniot curve for a given altitude shows the combinations of peak pressure and peak density that are possible behind a shock front moving into undisturbed air, i.e., into air that is initially at the ambient pressure and density corresponding to that altitude. Curves that show the value of γ assigned to the air just behind the shock front cross the graph as nearly horizontal lines. The curves that cut diagonally across the graph show absolute pressure (not overpressure) just behind the shock front. The ordinate of the graph is shock strength, which was defined in paragraph A-3.

A-6 Equations for Strong Shock Waves in Air [redacted]

[redacted] For shock strengths of 10 or more, accurate calculations must use the nonideal equation

[redacted]

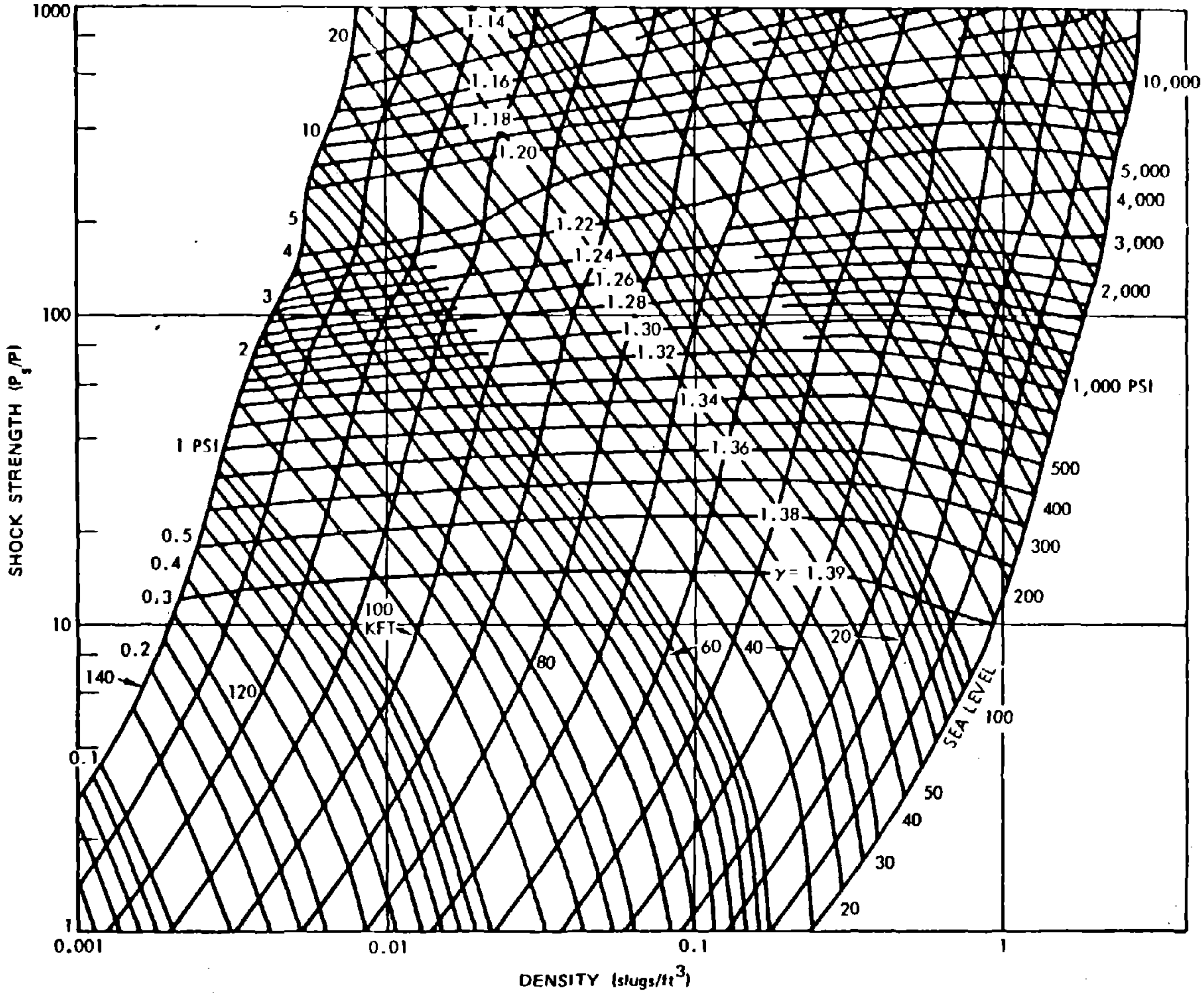

Figure A-2. [redacted] Equation of State Data for Air [redacted]

[redacted]

[redacted] of state data from Figure A-2. The appropriate shock wave equations are derived in the same manner as those shown in Table A-1. The principal difference is that two values of γ appear, γ for the air ahead of the shock and γ_s for the air just behind the shock front; the values in general are not equal. The shock wave equations for strong shock waves in air are listed in Table A-3. Two approximate velocity equations, accurate to within about 5 percent for shock strengths greater than 5, are shown on the right. As in Table A-1, the subscript *s* refers to parameters behind the shock front, and symbols with no subscript refer to ambient conditions.

[redacted] Note that shock strength ξ is a direct function of the absolute pressure P_s behind the shock front, rather than of Δp, the overpressure.* A shock strength of 1 therefore represents a vanishingly weak shock wave: and, at sea level, a shock strength of 2 represents an *overpressure* of 14.7 psi. Values for γ_s must be obtained from the equation of state data in Figure A-2.

*[redacted] This definition is not universal; shock strength is defined in some reports as $\Delta p/P$.

Table A-3. [redacted] Equations for Strong Shock Waves [redacted]

Complete Equation:	High-Shock-Strength Approximation:
Velocity of the Shock Front	
$U = c\left(\dfrac{(\xi - 1)(1 + \mu_s\xi)}{\gamma[\xi(\mu_s - 1) - (\mu - 1)]}\right)^{1/2}$	$U = c\left(\dfrac{\xi(\gamma_s + 1)}{2\gamma}\right)^{1/2}$
Particle Velocity Behind the Shock Front	
$u = c\left(\dfrac{(\xi - 1)[\xi(\mu_s - 1) - (\mu - 1)]}{\gamma_0(1 + \mu_s\xi)}\right)^{1/2}$	$u = c\left(\dfrac{2\xi}{\gamma(\gamma_s + 1)}\right)^{1/2}$
Density Ratio Across the Shock Front	
$\dfrac{\rho_s}{\rho} = \dfrac{1 + \mu_s\xi}{\mu + \xi}$	
Dynamic Pressure Behind the Shock Front	
$q_s = \dfrac{1}{2}P(\xi - 1)\left(\dfrac{1 + \mu_s\xi}{\mu + \xi} - 1\right)$	

where

$$\mu_s = \frac{\gamma_s + 1}{\gamma_s - 1}, \quad \mu = \frac{\gamma + 1}{\gamma - 1}, \quad \xi = \frac{P_s}{P} = \left(\frac{\Delta p + P}{P}\right), \quad \gamma = 1.4$$

[redacted]

SECTION II

[redacted] PHYSICAL DESCRIPTION OF SHOCK WAVE BEHAVIOR [redacted]

[redacted] Newton's second law, which relates force to the change in momentum that it produces, provides straightforward explanations of many shock wave phenomena. In particular, it explains certain reflection phenomena and the way in which these phenomena determine the forces produced by a blast wave when it strikes a surface or a small object.

[redacted] Acoustic theory also provides explanations of blast phenomena. These explanations are important because they appear frequently in discussions of shock wave reflection. The following discussion relates the acoustic theory explanations with those that are based on Newton's second law.

A-7 Step Function Shock Wave [redacted]

[redacted] In most respects, the properties of the shock front are independent of the shape of the pressure waveform that follows the front. Shock wave phenomena, therefore, can be explained in terms of the simplest possible waveform: a region of completely uniform pressure, density, and particle velocity behind a planar shock front. In such a wave, the shock front usually is considered a mathematical discontinuity, in which the pressure, velocity and other parameters are step functions of position and time.

[redacted] This type of simple shock wave may be generated by the mechanism shown in Figure A-3. A piston moves at constant velocity in a frictionless cylinder (a piston velocity of 431 ft/sec, a number that will be used later for purposes of illustration, produces a shock wave with

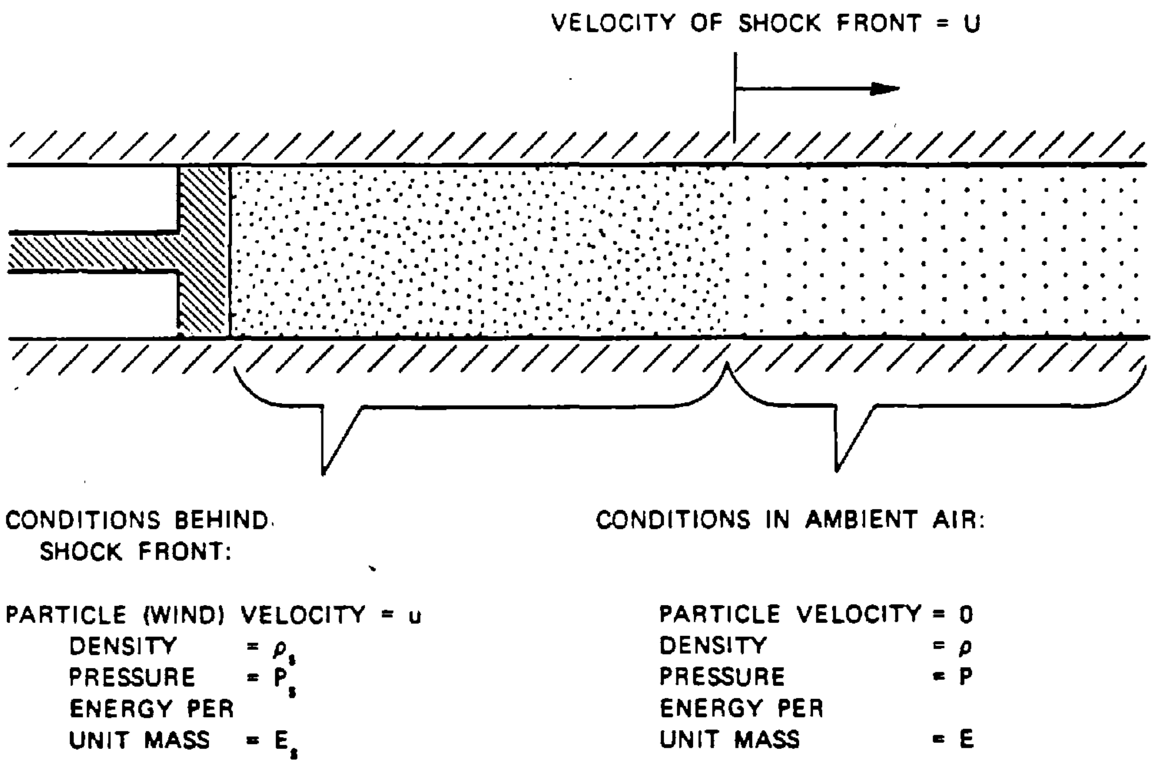

Figure A-3. [redacted] Idealized Shock Wave [redacted]

[redacted]

[redacted] an overpressure of 10 psi). The compressed air that constitutes the shock wave is uniform in density, pressure, and velocity.

[redacted] The step function shock wave differs from the blast wave from a nuclear burst in that the latter: (1) becomes weaker as it propagates away from the burst; (2) produces a decaying rather than a constant overpressure after the shock front passes a given point; and (3) has a spherical rather than a planar shock front. However, these differences are unimportant in the development of most of the concepts that apply to the shock front. As a result of its long overpressure duration, the blast wave from a high yield nuclear weapon is in many respects comparable to the idealized shock wave of Figure A-3.

A-8 Shock-Front Formation [redacted]

[redacted] The piston shown in Figure A-3 will require an interval of time to reach its final velocity. While it is accelerating, the pressure at the face of the piston will increase steadily. The pressure wave that the piston generates during this time lacks the abrupt pressure rise characteristic of a shock; however, differences in the velocities of different parts of the pressure wave ultimately will cause a shock front to form. Small pressure disturbances travel at the local speed of sound. In the air compressed by the piston, two factors cause this speed to differ from the speed of sound in ambient air; (1) compression of the air raises the air temperature, thereby increasing the speed of sound; (2) in moving air, pressure disturbances move with a velocity that is the vector sum of the air and sound velocities.

[redacted] As the piston starts to move, it creates an initial pressure disturbance that propagates ahead of the piston (to the right in Figure A-3) with a velocity equal to the velocity of sound in ambient air. By the time the piston reaches its final velocity, it will have produced a pressure wave that can propagate considerably faster than the ambient speed of sound. The wave produced by the high pressure just ahead of the piston soon overtakes the lower pressure wave, and a shock front is formed.

[redacted] After steady-state conditions are reached, the shock front moves at supersonic velocity with respect to the undisturbed air but at subsonic velocity with respect to the air behind the shock front. Ahead of the shock front, there is no early pressure increase to indicate the impending arrival of the shock wave. If such an early pressure wave were present, the shock front would overtake it. Behind the shock front, whatever pressure irregularities that may form can overtake the front and merge with it. The tendency for all pressure gradients to concentrate at the shock front is so strong that moderately strong shock waves in air generate shock fronts that are only a few atomic mean free paths (mfp) thick (at sea level, 1 mfp is about 10^{-5} cm).

A-9 Pressure-Momentum Interaction at a Shock Front [redacted]

[redacted] Before applying Newton's second law to a reflection problem, it will be examined with respect to a step function shock wave shown in Figure A-4. This is a simple problem that requires little more than a sample calculation. It is, however, useful as a preparation for the reflection problem that is discussed below. Numerical values of pressure, density, and velocity, calculated from the equations in Table A-1, appear in the figure.

[redacted] To evaluate Newton's second law, it is necessary to determine the momentum change per unit time and the force that produces the change. If a unit area of the shock front is considered, the force is numerically equal to the shock wave overpressure Δp, which in this example is 10 psi. To obtain a consistent set of units, this pressure must be expressed as 1,440 lbs/ft^2.

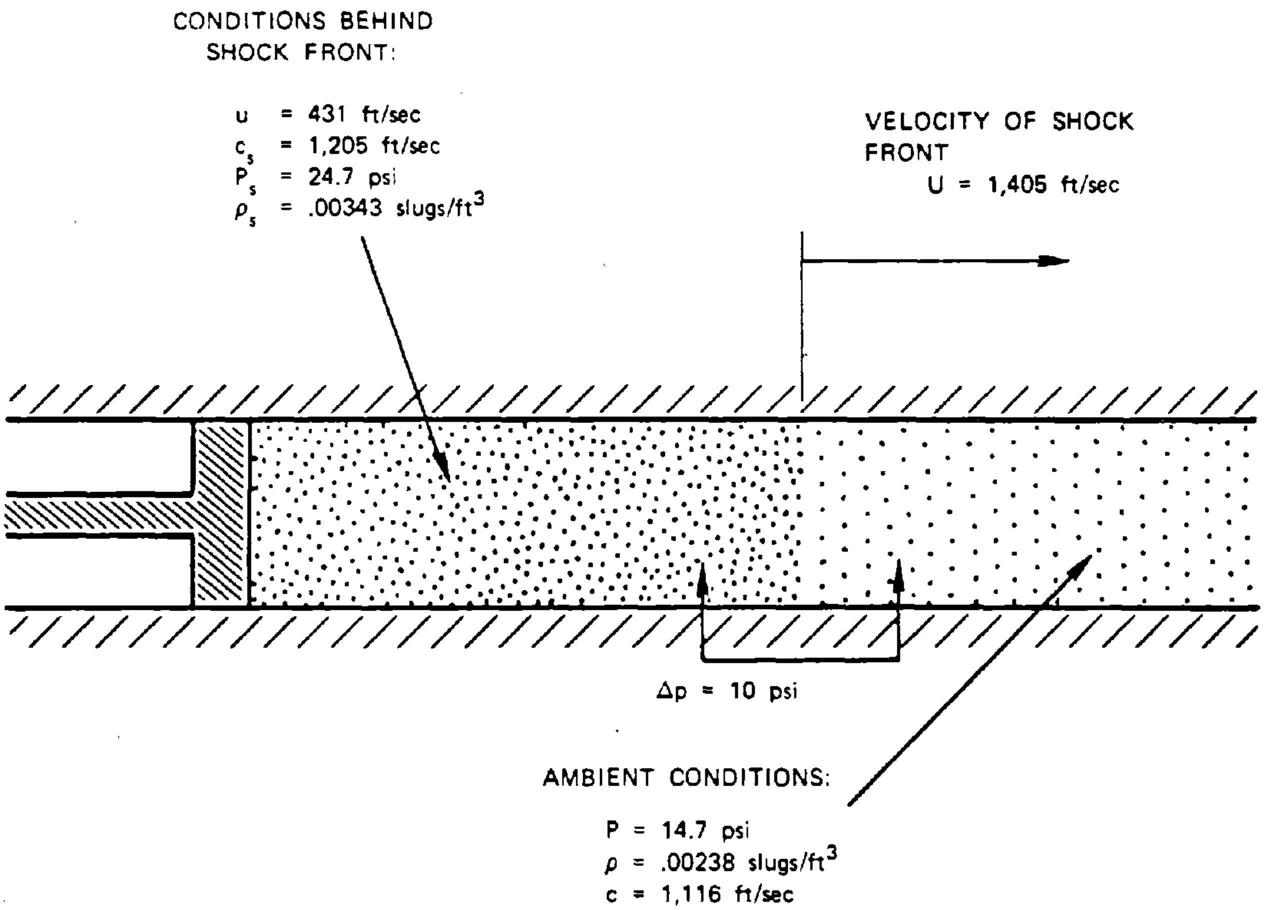

Figure A-4. [redacted] Parameters of a 10 psi Shock Wave [redacted]

[redacted] The mass of air that enters one square foot of shock front area each second is the ambient density, .00238 slugs/ft^3, times the shock front velocity of 1,405 ft/sec. This air is given a velocity of 431 ft/sec as it enters the shock wave. Thus,

$$\Delta p = \rho U u, \text{ or}$$

$$1{,}440 = .00238 \times 1{,}405 \times 431$$

A-10 Normal Reflection at a Solid Barrier [redacted]

[redacted] Figure A-5 shows a 10-psi shock wave that has struck the end of the cylinder and has formed a receding shock wave. Behind the receding shock front, the air is stationary. The velocity change at the reflected shock front has the same magnitude (but the opposite direction) as the velocity change of 431 ft/sec at the incident shock front. However, the pressure jump Δp_1 across the reflected shock front is greater than Δp because more mass per second is involved (see Figure A-5). The difference results principally from the higher density of the air entering the shock wave, but also results from the greater relative velocity, 1,491 ft/sec, between the shock front and the incoming air.

[redacted]

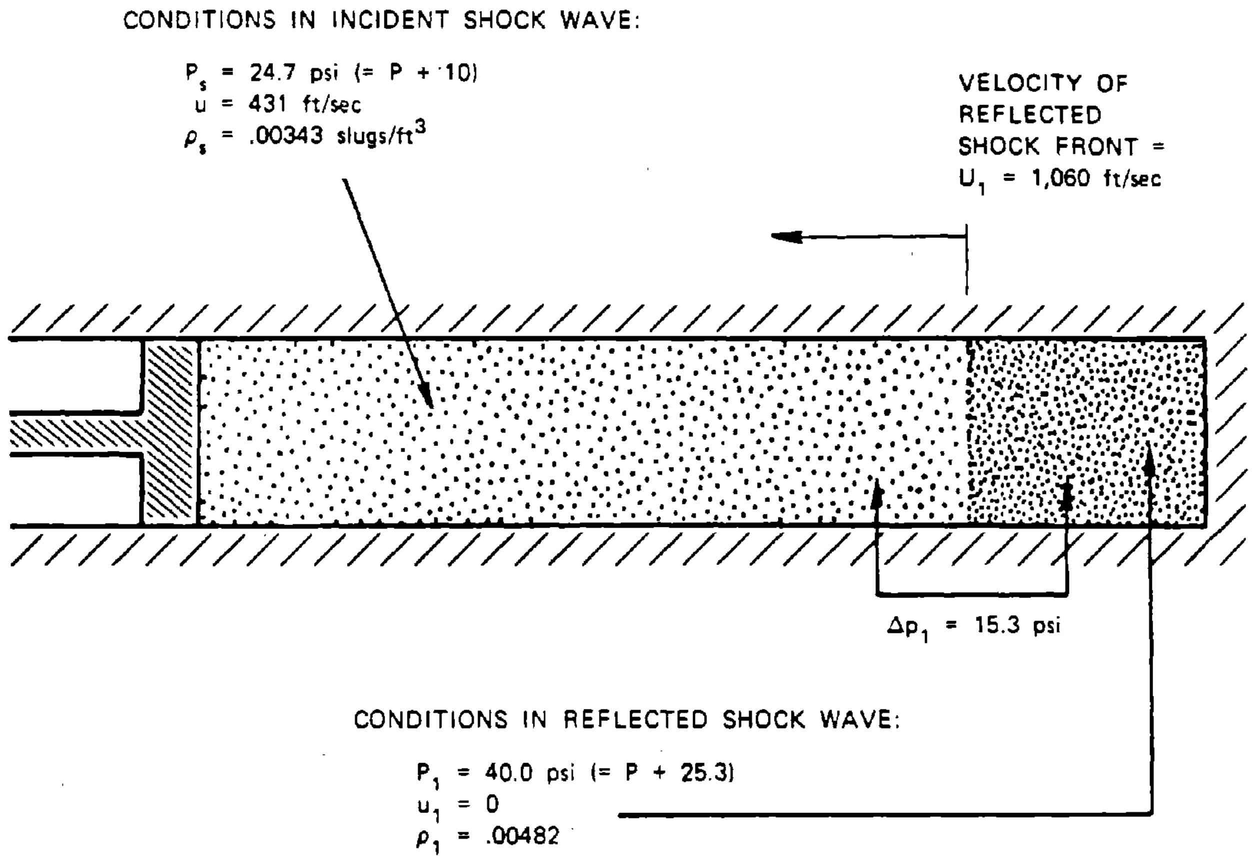

Figure A-5. [redacted] Reflection of a 10 psi Shock Wave from a Solid Barrier [redacted]

[redacted] The equation expressing Newton's second law may be obtained from basic physical principles, or it may be obtained from equations given in Section I by changing the frame of reference to one that is stationary with respect to the air ahead of the reflected shock front.

$$\Delta p = \rho U u,$$

$$15.3 \times 144 = .00343\ (1{,}060 + 431)\ 431,$$

$$2{,}220 = .00343 \times 1{,}491 \times 431$$

[redacted] The reflected overpressure, Δp_r, is the amount by which the pressure at the reflecting surface exceeds ambient pressure. It is the sum of the pressure jumps across the incident and the reflected shock fronts, or 25.3 psi.

[redacted] Acoustic theory often draws on the useful concept of images to explain the shock wave patterns produced at a reflecting surface. The reflecting surface is equivalent to a plane of symmetry. In the foregoing example, the image created by the reflecting surface would be a second piston, moving to the left with a velocity of 431 ft/sec, and located as far to the right of the reflecting surface as the real piston is to the left of it. As the two shock waves of equal strength collide, they produce conditions equivalent to those shown in Figure A-5.

[redacted]

[redacted] Explanation of the strength of the reflected shock front does not follow as readily from acoustic theory as does the basic shock wave pattern. Acoustic theory began with the study of sound waves, which have such low amplitudes that air acts as a linear medium. In such a medium, pressures are additive, and the wave reflected by a perfect reflector has the same amplitude as the incident wave. Shock wave effects are decidedly nonlinear, as is shown in the preceding example.

[redacted] Acoustic theory explains that the pres[redacted]jump of 15.3 psi instead of 10 psi at the reflected shock front is caused by the effect of dynamic pressure. Mathematically, this is a convenient explanation. For shock strengths less than about 10, the equations

$$\Delta p_1 = \Delta p + 2.4\ q$$

and

$$\Delta p_r = 2\Delta p + 2.4\ q$$

give correct values for Δp_1, the pressure jump at the reflected shock front and Δp_r, the reflected overpressure. The constant 2.4 is valid for air subjected to low shock strengths. In general, the constant has the value $\gamma + 1$.

[redacted] Physically, however, the explanation is [redacted]cial. In the sense that dynamic pressure effects are the effects caused by the momentum of air in motion, Δp_1 is produced entirely by dynamic pressure. The basic acoustic theory fails to predict shock wave phenomena. Predictions are possible only from a modified theory, tailored to fix experimental facts, and experience in using this theory is necessary to use it successfully.

A-11 Pressures on Simple Shapes [redacted]

[redacted] Two examples will be used to illustrate [redacted]henomena that occur when a blast wave interacts with a target.

[redacted] The first example is the steady-state pressure pattern around a sphere placed in the path of the shock wave. Figure A-6 shows the nature of this pattern after the shock front has passed, and equilibrium conditions apply.

[redacted] This problem is more complex than the [redacted]scussed in paragraph A-10. The air particles directed exactly toward the center of the sphere reach the stagnation point, a point on the sphere at which the air is brought to rest, and the momentum that these particles give up may be calculated readily. All of the other air particles affected by the sphere behave in a more complicated way. They are slowed down and deflected, but they are not stopped.

[redacted] An order-of-magnitude equation for [redacted] may be obtained by assuming that all of the air directed toward the sphere is stopped. The momentum per unit area per unit time di-

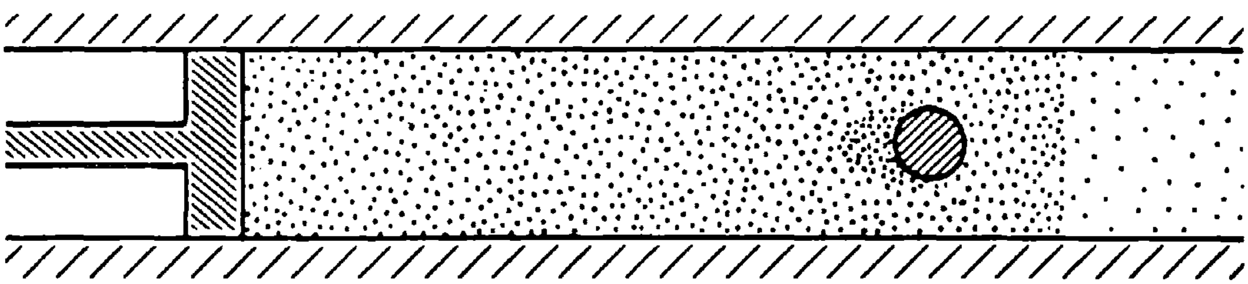

Figure A-6. [redacted] Reflection of a Shock Wave by a Small Object [redacted]

[redacted]

[redacted]

rected toward the sphere is $\rho_s u$ (the mass flow per unit area per unit time). Application of Newton's second law shows that the wind pressure is about

$$F/A = \rho_s u^2.$$

A detailed analysis would show that the pressure produced at the stagnation point of a sphere in a moderately strong wind is more closely approximated by dynamic pressure, which has a value that is just half of that given by the previous equation

$$q = \frac{1}{2} \rho_s u^2.$$

[redacted] Therefore, the wind pressure at the stagnation point on the sphere is roughly

$$q = \frac{1}{2} \times .00343 \times (431)^2,$$

$$= 318.58 \text{ lbs/ft}^2,$$

$$= 2.2 \text{ psi}.$$

Total pressure at the stagnation point is about 12.2 psi, the sum of the static overpressure and the dynamic pressure.

[redacted] The important point in this example is that the high pressure region around the object is stationary, not moving forward to meet the oncoming air as was the receding shock wave shown in Figure A-5. Consequently, the rate at which air enters the high pressure region is lower. The rate at which momentum is extracted from incoming air is correspondingly lower. By Newton's second law, the pressure developed is smaller.

[redacted] Acoustically, no reflection is considered to occur in this example. The problem is simply one of an object in an airstream.

[redacted] The second illustration is the transient interaction between a blast wave and a small cube. This type of interaction is largely a combination of those already discussed. For simplicity, the blast wave is assumed to strike one side of the cube head-on. Shortly after the shock front strikes the cube, the reflection process is much like that produced at the closed end of a piston (Figure A-5). A receding shock wave is formed, the mass flow rate into this shock wave is high, and the front face of the cube is subjected to a high reflected overpressure (25.3 psi for a 10 psi incident shock wave).

[redacted] At the edges of the front face of the cube, the layer of compressed air in the receding shock wave is unconfined. It flows outward, around the edges of the cube. This outward flow relieves the high pressure behind the receding shock front. As a result of this pressure relief, the receding shock front loses velocity; consequently, the incoming air gives up its momentum at a decreasing rate. A steady-state flow pattern develops, and the pressure at the front surface of the cube drops to roughly the incident overpressure plus the incident dynamic pressure. The situation is now similar to that shown in Figure A-6.

[redacted] Part of the acoustic explanation is very descriptive. Pressure relief waves form at the edge of the front surface of the cube and propagate inward. Reflections that occur when these relief waves meet increase the rate of flow over the front face and around the edges of the cube. The time required for the steady-state flow pattern to develop is about two or three times that required for a shock wave to travel from the edge of the cube to the center of the front face.

[redacted] The remainder of the acoustic explanation is evident only to a person familiar with acoustic theory or to a person who has previously encountered this particular explanation. It involves understanding: (1) the reflection coefficient of an object becomes small as the wave-

[redacted]

[redacted] length of the incident sound wave becomes large compared with the dimensions of the object; and (2) a pressure waveform has an equivalent spectrum of sound waves of different wavelengths (strictly speaking, the equivalent spectrum requires a linear medium and is only an approximation in strongly shocked air).

[redacted] These acoustic concepts, applied to the problem of reflection from a small cube, predict that the cube will reflect the shock front strongly, but that the reflection coefficient of the cube will decrease rapidly after the shock front passes. The reflected wave weakens by spherical divergence as it propagates away from the cube, and the pressure on the front face of the cube decreases to its steady-state value.

A-12 The Rankine-Hugoniot Equations (Alternate Analysis) [redacted]

[redacted] In the conventional derivation of the Rankine-Hugoniot equations (paragraph A-1), the algebra tends to obscure the physical picture associated with the derivation. The following analysis provides a more intuitive introduction to the subject.

[redacted] *The interaction at the shock front is basically an inelastic collision.* The truth of this statement is evident from the definition of an inelastic collision. It is a collision in which the colliding bodies stick together and move with a common velocity after they collide.

[redacted] The statement given above provides a method to account for the energy exchanges that occur at the shock front. It may be applied most readily if the collision is considered to occur between a very thin layer of unshocked air and the mass of air behind the shock front. The following statement may then be confirmed readily.

[redacted] *The inelastic collision at the shock front is 50 percent efficient in transferring kinetic energy to the incoming air.* A change to the center-of-mass frame of reference is the first step necessary to demonstrate this fact. Since the mass of air being picked up at any instant is infinitesimal, this frame of reference moves with the air behind the shock front. The initial kinetic energy per unit area of the shock front is, in this frame of reference, that of the thin layer of unshocked air approaching the shock front with a relative velocity of u. If its mass is dm, its initial kinetic energy is*

$$d(KE) = \frac{1}{2} u^2 dm.$$

After a completely inelastic collision, the kinetic energy in the center-of-mass frame of reference is zero.† In other words, the amount of energy that is converted from kinetic energy to internal energy in the collision is equal to $d(KE)$.

[redacted] In the original frame of reference (sta[redacted]y with respect to the unshocked air), $d(KE)$ is equal to the kinetic energy of the thin layer of air after it has become a part of the shock wave. Thus, the kinetic energy imparted to the air and the kinetic energy converted to internal energy by the inelastic collision are equal, i.e., this method of transferring kinetic energy is 50 percent efficient.‡

[redacted] Accounting for all of the work done at th[redacted]shock front is complicated by an energy ex-

[redacted] rigorous derivation of the equations governing the inelastic collision of two bodies requires the simultaneous solution of the energy and momentum equations of the system. If a large mass and a very small mass are approaching one another with equal and opposite momenta, the kinetic energy of the larger mass is negligible compared to the kinetic energy of the smaller mass.

[redacted] By definition, total momentum in the center-of-mass frame [redacted]eference is zero. Since momentum is conserved in the collision of two bodies, the total momentum remains zero after any collision. After a completely inelastic collision, neither of the colliding bodies is moving with respect to the center of mass; therefore, their final kinetic energy in this frame of reference is zero.

[redacted] Although kinetic energy changes with changes in the frame [redacted]eference, the energy loss in an inelastic collision does not.

[redacted] change that is independent of the exchange produced by the inelastic collision. The total work done on a unit mass of incoming air results from the pressure P_s that is behind the shock front moving through the distance required to compress this mass of air from its initial volume V to its final volume V_s.

$$W'_{total} = P_s(V - V_s).$$

One portion of this work is done by the ambient pressure P in displacing the volume $V - V_s$. Since the ambient pressure does not produce a force that has directional characteristics, it has no function in setting the air in motion. This portion of the work only contributes to compression.

$$W'_{comp} = P(V - V_s)$$

The remainder of the work is done by the overpressure $\Delta p = P_s - P$, displacing the volume $V - V_s$. At the shock front, the effect of overpressure is completely directional, and overpressure creates the force that accelerates the air that is overtaken by the shock front. This is the portion of the work that is required to produce kinetic energy by a collision process,

$$W'_{coll} = (P_s - P)(V - V_s).$$

As already demonstrated, half of this work appears as kinetic energy and half as internal energy of the unit mass of air added to the shock front. Note that the work converted to internal energy by the collision process is closely related to W_{comp} in that both contribute to compressing the gas to the volume V_s and, in this way, both increase the internal energy of the air.

[redacted] The energy exchange equations for a unit mass of air entering the shock front follow directly from the discussion in the preceding paragraph. The kinetic energy added to the unit mass of air is

$$\frac{1}{2}u^2 = \frac{1}{2}W'_{coll},$$

$$= \frac{1}{2}(P_s - P)(V - V_s).$$

and the particle (wind) velocity is

$$u = \left((P_s - P)(V - V_s)\right)^{1/2}.$$

The change in internal energy of the unit mass of air is

$$E_s - E = W'_{comp} + \frac{1}{2}W'_{coll}$$

$$= P(V - V_s) + \frac{1}{2}(P_s - P)(V - V_s)$$

$$= \frac{1}{2}(P_s + P)(V - V_s).$$

To obtain the equation for shock front velocity, note that while the air in the shock wave moves into a volume $V - V_s$, the shock front has advanced through a volume V. The ratio of shock front velocity to particle velocity is therefore

$$\frac{U}{u} = \frac{V}{V - V_s}$$

$$U = \left(\frac{V}{V - V_s}\right)\left((P_s - P)(V - V_s)\right)^{1/2}$$

$$U = V\left(\frac{P_s - P}{V - V_s}\right)^{1/2}.$$

The equations for u, $(E_s - E)$, and U are the Rankine-Hugoniot equations given previously in paragraph A-1.

[redacted] *Note:* Although the interaction at the shock front is completely inelastic, the overall reaction of a blast wave in free air is partially elastic. In such a blast wave, the pressure behind the shock front is not constant, but decays with time. The air behind the front expands and returns energy that helps to propagate the shock wave (see footnote to paragraph 2-33, Chapter 2). This fact does not alter the validity of the argument presented above. It simply points out that the inelastic collision at the shock front only describes part of the mechanism of blast wave propagation.

A-13 Dynamic Pressure [redacted]

[redacted] Dynamic pressure is frequently equated to the wind force produced on a target by the high velocity winds in a blast wave, but the relation between force and dynamic pressure is not this simple.

[redacted] One source of confusion is the name which implies a meaning that differs from the correct one. In a compressible fluid, the true meaning of dynamic pressure is limited to the mathematical definition

$$q = \frac{1}{2} \rho_s u^2$$

where ρ_s is mass per unit volume and u is particle velocity behind the shock front. Strictly speaking, q is not a pressure. A body moving along with moving air will not feel a force that is attributable to dynamic pressure. Dynamic pressure is kinetic energy per unit volume. Reasons for calling it a pressure are: (1) it has the dimensions of pressure; and (2) this energy can be used to develop a pressure.

[redacted] A stationary body exposed to a wind will experience pressures that differ at different points on its surface. The highest pressure on the body is the stagnation pressure, which occurs wherever the air is completely stopped by impact with the body. For example, if the body is a sphere, the stagnation pressure occurs at the point on the surface that faces directly into the wind. For an incompressible fluid, stagnation pressure is simply the sum of the free-stream static pressure and the free-stream dynamic pressure. However, for a compressible fluid, such as air, stagnation pressure is the sum of the free-stream static pressure and a quantity called the free-stream *impact pressure.* At low velocities, impact pressure and dynamic pressure are essentially equal, but at velocities that are appreciable compared with sound speed, impact pressure rises above dynamic pressure. When wind speed is equal to sound speed, impact pressure exceeds dynamic pressure by about 28 percent.

[redacted] The forces exerted by strong winds correspond more directly to impact pressures than to dynamic pressure. This suggests that weapons effects calculations should be based on impact pressures rather than on dynamic pressures: but, both in this field and in aerodynamics, dynamic pressures are employed more commonly. The choice is based on conventional practice. In aerodynamic problems, dynamic pressure is used because it may be calculated readily. Wind force on an object is calculated from the equation

$$F_w = C_D q A$$

where C_D is drag coefficient and A is an area related to the size of the object. The drag coefficient is not constant. It is a function of velocity, and its variation absorbs not only the discrepancy between dynamic pressure and impact pressure, but also accounts for the net effect of the complex pressure pattern that forms around an object in an airstream. The product qA, although it has the dimensions of a force, has no direct physical relation to any force exerted by the wind.

[redacted] In weapons effects calculations, dynamic pressure often is as convenient as it is in aerody-

[redacted] namics: damage criteria for such objects as buildings are established in terms of conventional shock wave parameters, such as overpressure, dynamic pressure, or impulse. Consequently, the stagnation pressure or other actual pressures found at various points on specific structures usually are not calculated unless specific blast loading information is desired. In some cases, the choice of dynamic pressure may not be appropriate for damage criteria. For example, when the air in the blast wave is dust laden (as it is for certain combinations of yield, burst height, ground range, and surface properties), a measurement with a conventional dynamic pressure gauge often is ambiguous. The dust is not necessarily in velocity equilibrium with the air, and the amount of dust is not known. As a result, it is often difficult to calculate the dynamic pressure of air alone from such experimental measurements.

[redacted]

APPENDIX B

USEFUL RELATIONSHIPS [redacted]

B-1 General Equivalents [redacted]

[redacted] One kiloton (kt) is defined to be 10^{12} calories of energy release.* This amount of energy will be released by the complete fission of 0.057 kg (57 grams or 2 ounces) of fissionable material.† Equivalents to this amount of energy in other units are:

- 2.61×10^{25} million electron volts (MeV),
- 4.18×10^{19} ergs,
- 1.16×10^{6} kilowatt-hours,
- 3.97×10^{9} British thermal units.

[redacted] Some equivalents of the complete conversion of mass to energy are:

$$1 \text{ gram mass} = 5.61 \times 10^{26} \text{ MeV}$$
$$= 8.99 \times 10^{20} \text{ ergs}$$
$$= 2.15 \times 10^{13} \text{ calories}$$

[redacted] The temperature associated with one e[redacted]on volt is 11,605.9 degrees Kelvin.

B-2 Constants [redacted]

[redacted] Velocity of light: 3×10^{8} m/sec = 3 x 10[redacted] cm/sec.

[redacted] Avagadro's number: 6.023×10^{23} molecules per mole (gram molecular weight).

[redacted] Planck's constant: 6.625×10^{-27} erg-sec.

Boltzmann constant: 1.38×10^{-16} erg/°K.

[redacted] ‡Mass of electron: 9.1085×10^{-28} gm.

‡Mass of proton: 1.672×10^{-24} gm.

‡Mass of neutron: 1.675×10^{-24} gm.

‡Mass of alpha particle: 6.64×10^{-24} gm.

Loschmidt number: 2.687×10^{19} molecules of ideal gas per cubic centimeter at °C.

[redacted] Electron charge:

$$4.803 \times 10^{-10} \text{ esu} = 1.602 \times 10^{-20} \text{ emu}$$
$$= 1.602 \times 10^{-19} \text{ coulombs.}$$

B-3 Standard Sea Level Atmosphere [redacted]

[redacted] Pressure = 14.696 psi
= 2,116.22 lb/ft^2
= 1,013.25 millibars
= 101,325. newtons/m^2
= 1,013,250. dynes/cm^2

[redacted] Temperature = 59°F
= 15°C
= 288.15°K
= 518.4°R

[redacted] Density = 2.38×10^{-3} slug/ft^3
= 7.65×10^{-2} lb/ft^3
= 1.225×10^{-3} gm/cm^3
= 1.225 kg/m^3

[redacted] Speed of sound = 1,116.45 ft/sec
= 340.29 m/sec
= 34,029 cm/sec

[redacted] See footnote on page 1-3 for the origin of the definition.

†[redacted] This is the energy released by the *fission* of 57 grams of fissionable material. It is *not* the energy that would be released by the conversion of 57 grams mass to energy.

[redacted] Classical rest mass.

[redacted]

[redacted] Gravitational acceleration
= 9.8067 m/sec^2
= 32.1741 ft/sec^2

B-4 Conversions [redacted]

[redacted] Length:

1 ft	= 0.3048 m
	= 30.48 cm
1 m	= 3.281 ft
1 kft	= 0.3048 km
	= 0.1894 mi
	= 0.1645 nm
1 km	= 1,000 m
	= 3,281 ft
	= 3.281 kft
	= 0.6214 mi
	= 0.5396 nm
1 mi	= 5,280 ft
	= 1,760 yds
	= 5.280 kft
	= 1.609 km
	= 0.8684 nm

[redacted] Force:

1 dyne = 1.0197 x 10^{-3} gm (weight)
= 2.2481 x 10^{-6} lb (weight)

1 gm (weight)	= 980.665 dynes
	= 2.2046 x 10^{-3} lb (weight)
	= 1 x 10^{-3} kg (weight)
1 lb (weight)	= 4.4482 x 10^5 dynes
	= 453.59 gm (weight)
	= 0.45359 kg (weight)

[redacted] Pressure:

1 dyne/cm^2	= 1.0197 x 10^{-3} gm/cm^2
	= 1 x 10^{-1} newtons/m^2
	= 7.5 x 10^{-4} mm mercury (0°C)
	= 4.015 x 10^{-4} in. water (4°C)
	= 2.089 x 10^{-3} lb/ft^2
	= 1.451 x 10^{-5} lb/in.^{2} (psi)
	= 1.02 x 10^{-2} kg/m^2
	= 1 x 10^{-3} millibars
1 gm (wt)/cm^2	= 980.665 dynes/cm^2
	= 980.665 x 10^{-1} newtons/m^2
	= 10.0 kg/m^2
	= 2.048 lb/ft^2
	= 1.422 x 10^{-2} lb/in.^{2} (psi)
	= 7.35 x 10^{-1} mm mercury (0°C)
	= 0.394 in. water (4°C)
	= 980.665 x 10^{-3} millibars
1 lb (wt)/in.^{2} (psi)	= 6.895 x 10^4 dynes/cm^2
	= 6.895 x 10^3 newtons/m^2
	= 703.07 kg/m^2
	= 70.307 gm/cm^2
	= 51.715 mm mercury (0°C)
	= 27.673 in. water (4°C)
	= 68.947 millibars
1 millibar	= 100 newtons/m^2
	= 1,000 dynes/cm^2
	= 1.45 x 10^{-2} lb/in.^{2}
	= 2.089 lb/ft^2

[redacted] Density:

1 gm/cm^3	= 1,000 kg/m^3
	= 3.613 x 10^{-2} lb/in.^{3}
	= 62.43 lb/ft^3
	= 1.94 slugs/ft^3
1 kg/m^3	= 1 x 10^{-3} gm/cm^3
	= 3.613 x 10^{-5} lb/in.^{3}

[redacted]

	= 6.243×10^{-2} lb/ft^3
	= 1.94×10^{-3} slugs/ft^3
1 lb/ft^3	= 1.6018×10^{-2} gm/cm^3
	= 16.018 kg/m^3
	= 5.787×10^{-4} lb/in.^{3}
	= 3.108×10^{-2} slugs/ft^3
1 slug/ft^3	= 0.5154 gm/cm^3
	= 515.4 kg/m^3
	= 1.862×10^{-2} lb/in.^{3}
	= 32.174 lb/ft^3

[redacted] Energy:

1 gm-cal	= 4.184 joules
	= 4.184×10^{7} ergs
	= 3.086 ft-lb
	= 3.966×10^{-3} Btu
1 joule	= 1×10^{7} ergs
	= 0.239 gm-cal
	= 0.738 ft-lb
	= 9.480×10^{-4} Btu
1 erg	= 1×10^{-7} joules
	= 2.39×10^{-8} gm-cal
	= 7.38×10^{-8} ft-lb
	= 9.48×10^{-11} Btu
1 ft-lb	= 1.356 joules
	= 1.356×10^{7} ergs
	= 3.240×10^{-1} gm-cal
	= 1.285×10^{-3} Btu
1 Btu	= 252 gm-cal
	= 1,054 joules
	= 1.054×10^{10} ergs
	= 778 ft-lb

[redacted] Velocity:

1 cm/sec	= 1×10^{-2} m/sec
	= 3.281×10^{-2} ft/sec
	= 2.237×10^{-2} mi/hr
	= 1.942×10^{-2} knots
1 m/sec	= 100 cm/sec
	= 3.281 ft/sec
	= 2.237 mi/hr
	= 1.942 knots
1 ft/sec	= 30.48 cm/sec
	= 3.048×10^{-1} m/sec
	= 6.818×10^{-1} mi/hr
	= 5.921×10^{-1} knots
1 mi/hr	= 44.70 cm/sec
	= 0.4470 m/sec
	= 1.4667 ft/sec
	= 0.8684 knots
1 knot	= 51.48 cm/sec
	= 0.5148 m/sec
	= 1.689 ft/sec
	= 1.152 mi/hr

[redacted] Temperature:

°K	= °C + 273.15
°R	= °F + 459.4
°C	= 5/9 (°F − 32)
°F	= 9/5 °C + 32

[redacted] Wavelength:

1 Å	= 10^{-8} cm
	= 10^{-10} m
	= $10^{-4}\mu$
1μ	= 10^{-4} cm
	= 10^{-6} m
	= 10^{4} Å

B-5 Fractional Powers and Dimension Scaling [redacted]

[redacted] Figures B-1 and B-2 provide the information necessary to perform many of the fractional power scaling operations required by equations presented in this manual. The use of these figures is demonstrated in Problem B-1. Figure B-3 is a nomogram that shows the relationships among the height of burst, the horizontal distance, and the slant range. A straight line through any two (known) of these quantities (on the appropriate scale) will pass through the third (unknown) quantity on its scale. The three dimensions must, of course, be in the ~~same~~ appropriate units. The diagram accompanying this nomogram should make its use obvious, and no example is provided. While Figures B-1 through B-3 are plotted accurately, visual interpolation on these figures cannot provide accurate results. If tools such as a slide rule, logarithm tables, or a calculator that can perform fractional power operations are available, users of this manual are encouraged to make use of those tools. Figures B-1 through B-3 are provided for those who desire a reasonable answer in the absence of such tools.

[redacted]

Problem B-1. Use of Fractional Power Curves and Dimension Scaling Nomogram

[redacted] Figure B-1 shows several fractional powers of numbers between 1 and 100,000. The fractional powers are those that are necessary to apply various scaling procedures presented elsewhere.

[redacted] Figure B-2 is a nomogram from which actual dimensions may be obtained from various scaled dimensions for yields from 0.1 kt to 100 Mt. The scaling power for which the scaled dimensions are applicable is indicated at the top of the scale in each case. A straight line connecting a yield with any scaled dimension will cross the actual dimension scale at the proper value according to the scaling which is being used. The dimensions may be in any units for which scaling is given, but the scaled dimension and the actual dimension will always be in the same units.

[redacted] *Example 1* [redacted]

Given: A 500 kt weapon is to be burst at the minimum height of burst at which fallout is not expected. A conservative height of burst is desired.

Find: The actual height of burst at which the weapon is to be detonated.

Solution: From paragraph 5-22, the minimum conservative height of burst for a 500 kt weapon at which fallout is not expected is 180 $W^{0.4}$ ft.

Answer a: From B-1

$$(500)^{0.4} = 12$$

$$180 \times 12 = 2{,}160 \text{ ft.}$$

Answer b: From Figure B-2, a straight line connecting 500 on the yield scale with 180 on the 0.4 power scaled dimension scale crosses the actual dimension scale at 2,160. The desired height of burst is thus 2,160 feet. (*Note:* Conversion from one scaling procedure to another is particularly easy with the nomogram. The line mentioned above crosses the cube root scaled dimension scale at 270. Thus 180 $W^{0.4}$ ft corresponds to 270 $W^{1/3}$ ft for 500 kt.)

[redacted] *Example 2* [redacted]

Given: A ground distance of 2,580 yd from an 80 kt surface burst.

Find: The proper distance to determine overpressure from the 1 kt curves.

Solution: The applicable scaling is (Problem 2-9).

$$\frac{d}{d^1} = W^{1/3}.$$

Answer a: From Figure B-1

$$(80)^{1/3} = 4.3,$$

$$d_1 = \frac{d}{W^{1/3}} = \frac{2{,}580}{4.3} = 600 \text{ yd}$$

$$= 1{,}800 \text{ ft.}$$

Answer b: From Figure B-2, a straight line from 80 on the yield scale through 2,580 on the actual dimension scale intersects the cube root scaled dimension scale at 600. The scaled distance is 600 yards. The proper distance to enter the overpressure charts is 1,800 feet.

[redacted]

[redacted]

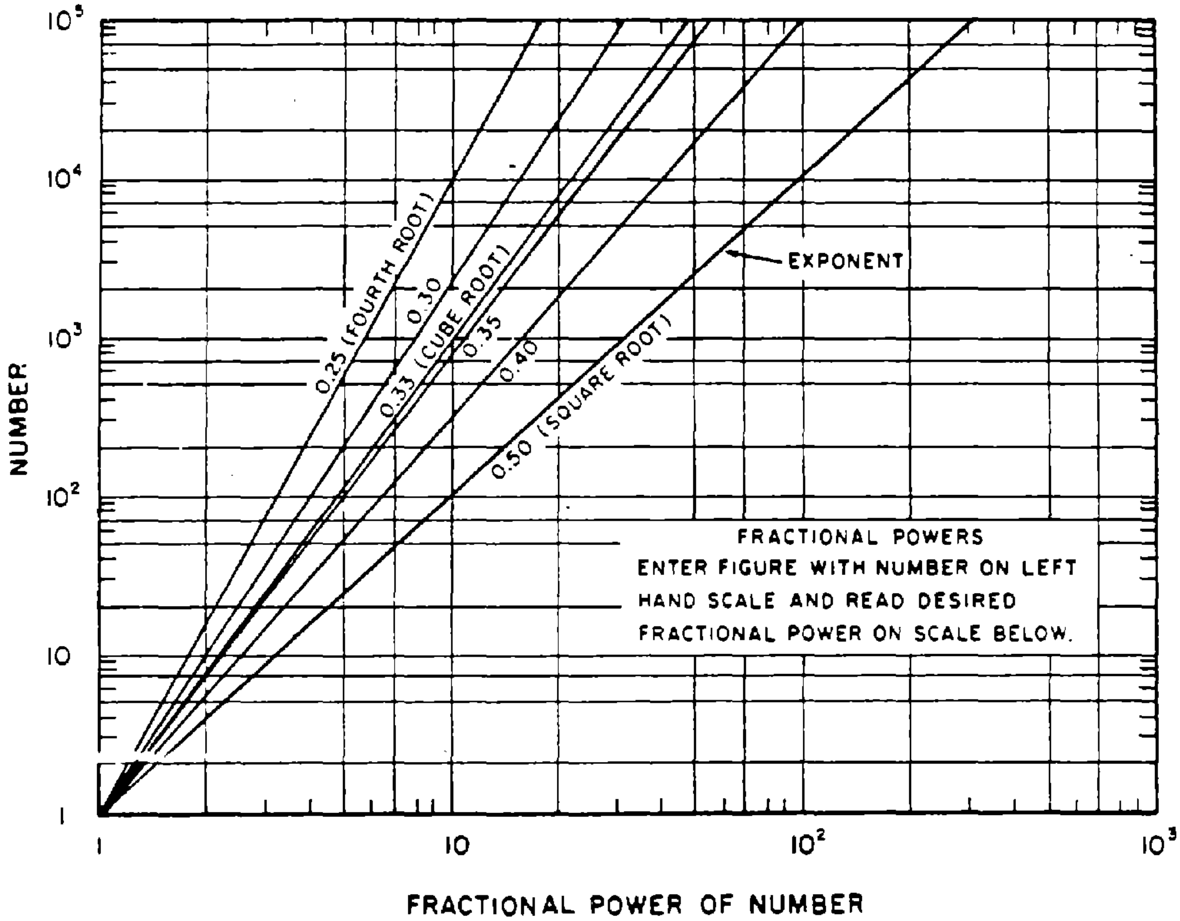

Figure B-1. [redacted] Various Fractional Powers of Numbers [redacted]

[redacted]

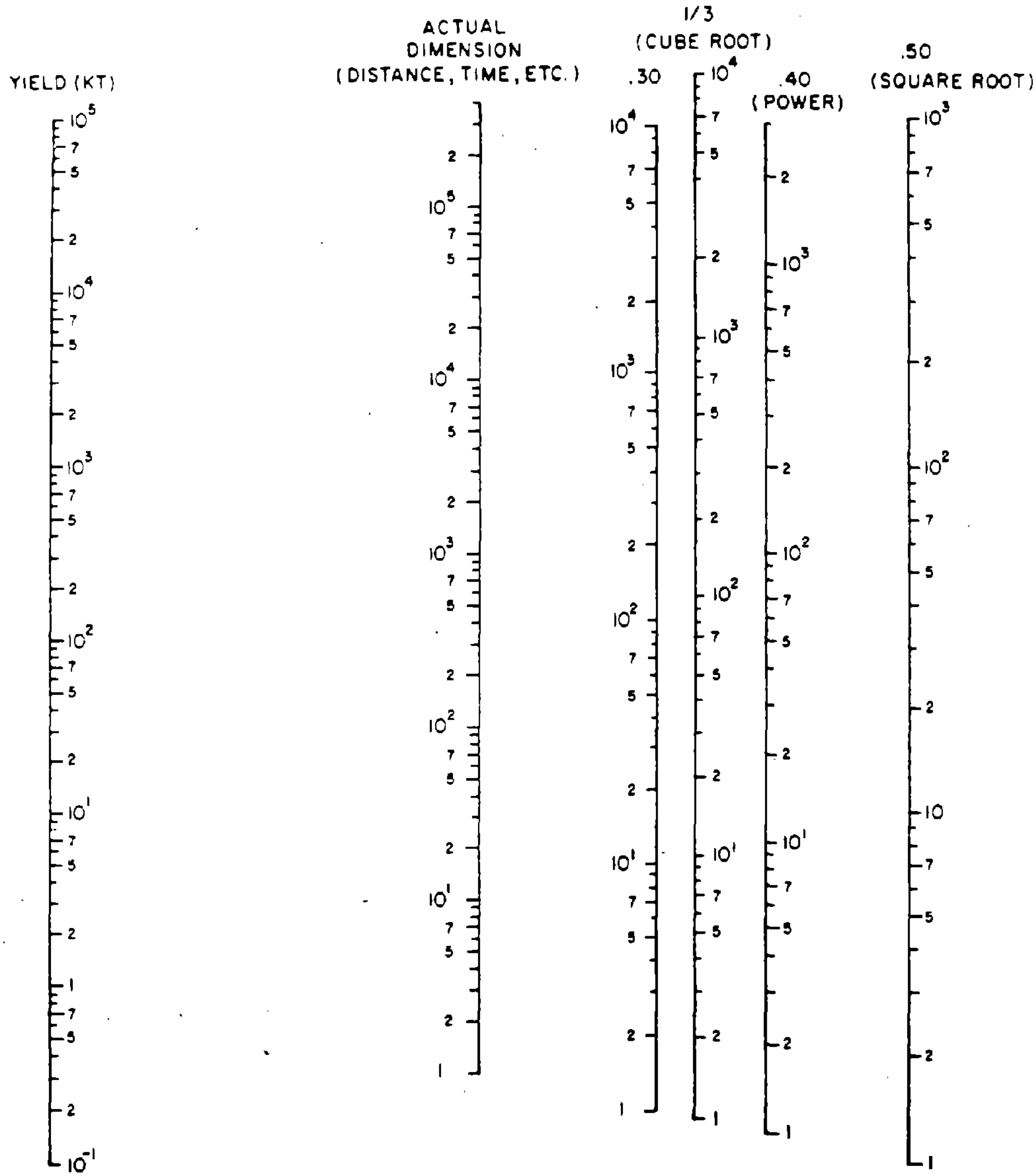

Figure B-2. [redacted] Dimension Scaling Nomogram [redacted]

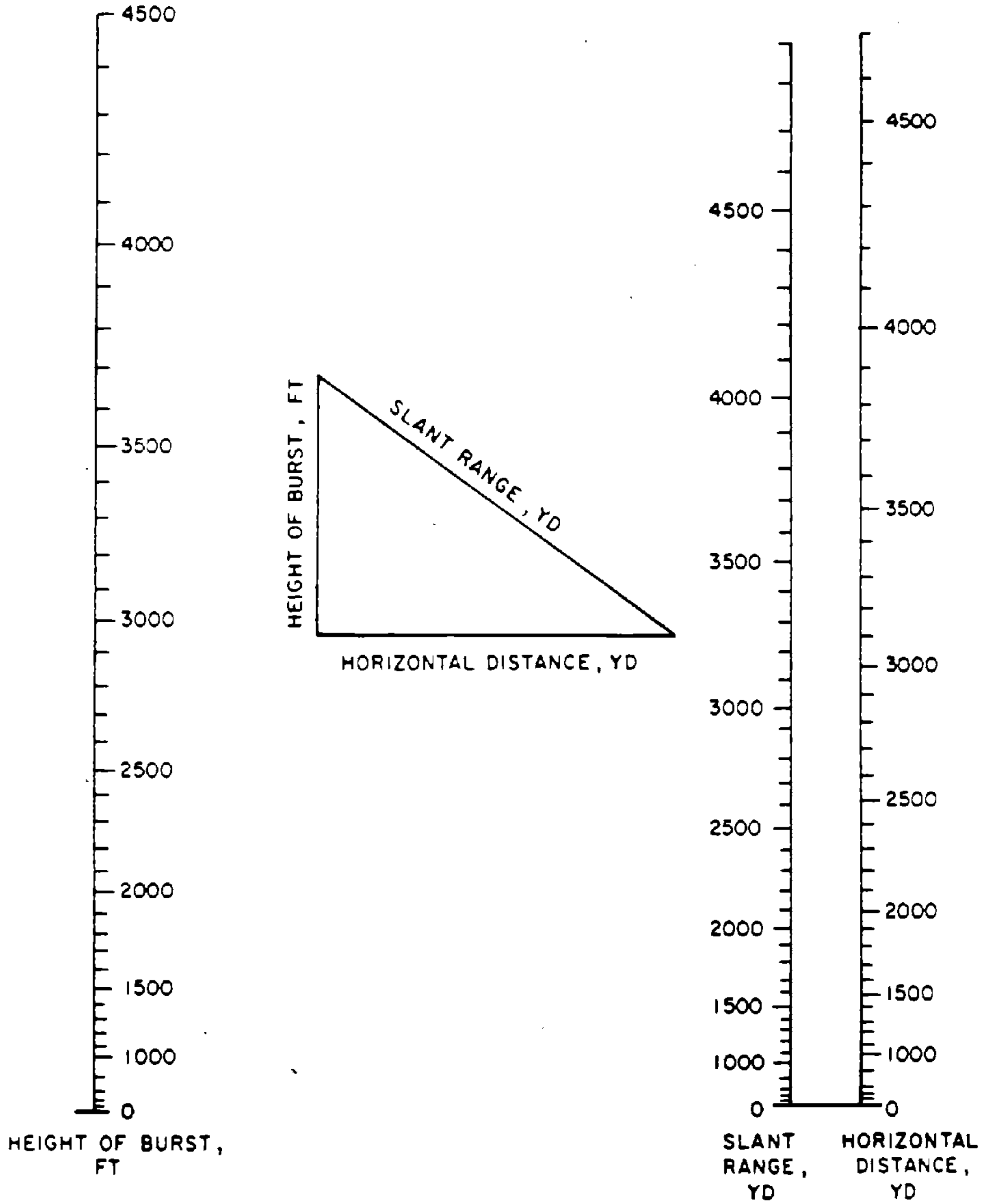

Figure B-3. [redacted] Height of Burst—Horizontal Distance—Slant Range Nomogram [redacted]

[redacted]

APPENDIX C

PROBABILITY CONSIDERATIONS [redacted]

[redacted] The procedures described in Sections I through III of Chapter 11 permit independent calculations of the 50 percent probability of damage to structures. equipment and personnel. Section I of this appendix provides a method for determining the probability of failure for conditions other than those considered in Chapter 11. i.e., where the median or 50 percent probability level of vulnerability differs from the median or 50 percent probability level of input motions or pressures. Section II provides the derivation of some equations used in Section I. Familiarity with Section III. Chapter 2 and Sections I through III, Chapter 11 is presupposed.

[redacted] The discussion herein is related to the intensity of motion (either displacement, velocity, or acceleration) that is required to produce severe damage to equipment or personnel, and to the intensity of input pressures produced by the air shock that will cause severe or moderate damage to both aboveground and belowground structures. The failure of rock openings is also treated in terms of slant range. Either free field values, or values within the structure at the point of support of the equipment, or the response spectrum values, may be used interchangeably as input. In general, the response spectrum values of motion will be used. Different probabilities will be obtained for shock effects depending on the knowledge available pertaining to the type and design of the shock mount.

[redacted] In all cases, the parameters that are dealt with are the intensity of motion, the intensity of overpressures, or the slant range. For motion vulnerability, one of the three elements of motion (displacement, velocity, or acceleration) can be used, depending on which region of the spectrum is involved, without otherwise distinguishing among them. By comparing the median value of input (motion, pressure, or slant range) with the median value of vulnerability, respectively, to motion, overpressure, or slant range as appropriate, the probability of failure or survival of the particular piece of equipment or structure can be obtained directly. When these two levels are equal, the probability of failure is, of course, 50 percent. However, when they are different, the tables and figures provided in this appendix may be used to obtain the probability of failure or of survival.

C-1 Protective Design and Weapon Selection [redacted]

[redacted] In general, all of the parameters governing the response of a structure, including the loading and the structural parameters, are subject to variation and uncertainty. In making a design of a structure to resist certain overpressures, or other inputs, for a particular yield of weapon, the designer ordinarily makes assumptions on the conservative side in all or nearly all of the cases where he has a choice of parameter values. The designer desires to state, with a high degree of confidence, that his structure will withstand an overpressure (the "design" overpressure), or other inputs, specified to him. He will, therefore, choose parameter values sufficiently conservative to assign a high confidence value to his statement, e.g., 90 percent or better.

[redacted] The weapon analyst who is estimating the vulnerability of a structure, on the other hand, can work with an overall variation, which reflects the variation of the individual parameters. The weapon analyst is not bound to the selection of single values for these parameters,

[redacted]

[redacted] because he is not solely interested in being able to state the probability that a single specified input will cause the desired damage, or that a certain input will cause damage with a high degree of confidence. Instead, he must answer the question, given a specified combination of weapon yield and height of burst, and considering the possible variations associated with the structural and weapon parameters, what is the probability that the specified damage will occur.

SECTION I

[redacted] DAMAGE PROBABILITIES [redacted]

[redacted] DAMAGE CAUSED BY MOTION INPUT [redacted]

C-2 Description of Charts for Damage Caused by Motion Input [redacted]

[redacted] Values of the standard deviation σ, stated in terms of a percentage of the mean value m of intensity of motion, are shown in Item 1 of Table C-1. These values represent the combination of variabilities and uncertainties relative to the shock motions as well as to the vulnerability of structures or equipment and personnel. The values apply equally for input displacement in the constant displacement region, or velocity in the constant velocity region and acceleration in the constant acceleration region (see Figures 2-90 and 11-51).

[redacted] Separate values are given for equipment that is not shock mounted and for equipment that is shock mounted. Different values are given for shock mounted equipment to distinguish between equipment where the design of the mount is known, and for two different situations for shock mounted equipment where the design is unknown. In the case where the design is unknown, the type of equipment may be known and therefore some better measure of the vulnerability level can be assessed; alternately, the type of equipment also may be unknown, and major uncertainties must be considered to exist in the data. The values of σ/m given in Items 1a through 1d reflect these degrees of uncertainties.

[redacted] The distributions of the combined vulnerabilities can be considered to be logarithmic normal, and to have the shape corresponding to the typical lognormal curve for the particular values of σ/m listed in Table C-1. The parameters of the lognormal probability distribution and its properties are summarized in Section II of this appendix.

[redacted] Figure C-1 shows the probability distributions for failure or for survival for the various combined values of σ/m stated in Table C-1, plotted as a function of the ratio of the median value of input motion (or input pressure or slant range), b_i, to the median value of vulnerability level of motion (or of pressure vulnerability or of slant range), for the equipment or structure, b_v. Figure C-2 is similar to Figure C-1, except that the ratio σ/m is shown as a function of b_i/b_v for different probability values. Where $b_i = b_v$, i.e., the ratio is unity, the probability of failure is 50 percent. These curves are used to obtain the probability of failure for any other ratio of b_i/b_v; as shown in Section II, these same curves give the probability of survival if the ordinates are taken as b_v/b_i in place of b_i/b_v. Therefore, the probability of failure or of survival can be determined by using the appropriate curve in Figure C-1 or C-2. For example, if a situation exists in which velocity governs the response (in the constant velocity region) and where the equipment is shock mounted (design known) with the mounting being the item in which failure is to be produced, the appropriate σ/m of 100 percent is obtained from Item 1b of Table C-1. With this value, it can be seen that if the median value of input velocity is 2.0 times the vulnerability velocity level, either Figure C-1 or Figure C-2 shows that the probability of failure is about 79 percent.

[redacted]

[redacted] If, however, the acceleration bound governs, and the shock mounting design is unknown but the type is known, Item 1c of Table C-1 shows σ/m to be 150 percent. With this value, if the median input acceleration is 2.0 times the vulnerability level of acceleration, the probability of failure is only 74 percent. To achieve an 85 percent probability of failure for this condition would require that the median value of acceleration be 3.1 times the vulnerability level of acceleration, as shown in Figure C-2.

C-3 Instructions for Motion Input Analyses [redacted]

[redacted] A step-by-step procedure for motion input analysis is given below. Illustrative examples for specific analyses are given in paragraph C-4. It is assumed that b_v is known and b_i for the particular weapon and conditions is assumed for motion inputs and vulnerability. The steps are:

1. Determine the value of σ/m from Table C-1 depending on whether or not an element is shock mounted and on the knowledge of the type and design of the mount.

2. If information other than that given in Table C-1 is available in the form of coefficients of variations of the input motions and of the vulnerabilities, the following equation can be used to obtain the combined σ/m:

$$\frac{\sigma}{m} = \left\{\left(\frac{\sigma_i}{m_i}\right)^2 + \left(\frac{\sigma_v}{m_v}\right)^2 + \left(\frac{\sigma_i}{m_i}\right)^2 \left(\frac{\sigma_v}{m_v}\right)^2\right\}^{1/2}.$$

If the parameters are different from those tabulated, and a value of σ/m computed from the above equation is different from any of those shown in Table C-1, enter Figure C-2 with the value of σ/m as abscissa, and read the value of b_i/b_v for a chosen probability of failure P_f (suggest P_f = 90 percent or 95 percent). With this value of b_i/b_v, a line can be plotted on Figure C-1 appropriate to the particular value of σ/m. The value of b_i/b_v is plotted on Figure C-1 as the ordinate at the chosen probability, P_f = 90 percent or 95 percent as the case may be. A line from the plotted point through the 50 percent point (where the other lines intersect) gives the entire curve. Alternately, if the combined value of σ/m is not given in Table C-1 or Figure C-1, Figure C-2 may be used in place of Figure C-1.

3. For the particular value of σ/m determined, read the probability of failure from Figure C-1 using the abscissa at the bottom of the figure, or the probability of survival using the abscissa at the top of the figure for the particular value of b_i/b_v.

4. For the given ratios of σ/m, and for any value of b_i/b_v, the probabilities of failure or of survival are determined as described above; however, Figures C-1 and C-2 also can be used with a ratio of b_v/b_i to give the same probabilities by interchanging P_f, the probability of failure, with P_s, the probability of survival.

5. If a particular probability of failure or survival is desired, the value of b_i/b_v is obtained from Figure C-1 or C-2 for the particular combined value of σ/m, and the desired value of b_i is obtained by trial-and-error for the particular given value of b_v.

C-4 Illustrative Examples for Motion Inputs [redacted]

Example 1 [redacted]

[redacted] Consider the vulnerability of non-shock mounted equipment. The value of b_v is assumed to be 10g at approximately 20 cycles per second. Consider the case in which the spectrum intersection is along a line parallel to a line of constant acceleration.

[redacted] From Table C-1, Item 1a indicates a value of σ/m of 100 percent.

[redacted] For a particular explosion, the acceleration level is determined to be b_i = 7g (by the

[redacted]

[redacted] methods of Section III, Chapter 2). Therefore, the ratio of b_i to b_v is 7/10 = 0.7. From Figure C-1, with b_i/b_v = 0.7 and σ/m = 100 percent, the probability of failure is 33 percent, or the probability of survival is 67 percent. Alternately, b_v/b_i = 1.43. Using this value of b_v/b_i and σ/m = 100 percent, the survival probability is read directly from Figure C-1 or C-2 to be 67 percent.

Example 2 [redacted]

[redacted] For the same conditions as example 1, determine the input acceleration that would be required to produce a 90 percent probability of failure.

[redacted] From Figure C-1 or C-2, a 90 percent probability of failure occurs for σ/m = 100 percent if b_i/b_v = 2.9. This means that an acceleration of 29g will be required to produce 90 percent probability of failure.

Example 3 [redacted]

[redacted] For the same equipment, consider a condition in which the equipment is shock mounted, with a velocity vulnerability of 1,000 in./sec at approximately 4 cycles. Failure is desired in the mounting for a known design of the mount.

[redacted] From Table C-1, Item 1b, σ/m = 100 percent.

[redacted] If the velocity level for the explosion conditions is determined to be 1,500 in./sec, the probability of failure from Figure C-1 or C-2 is 69 percent for b_i/b_v = 1.5 and σ/m = 100 percent.

[redacted] For the same conditions, a 95 percent probability of failure requires a value of b_i/b_v of 4.00, or a value of velocity of approximately 4,000 in./sec.

Table C-1. [redacted] Standard Deviations for Use in Probability Analyses [redacted]

Item	σ/m (percent of mean of reference parameter)	Reference Parameter
1. Shock effects on personnel and equipment:		
a. Not shock mounted	100	Shock motion
b. Shock mounted, design of mount known	100	Shock motion
c. Shock mounted, type of mount known, design unknown	150	Shock motion
d. Shock mounted, type of mount and design unknown	200	Shock motion
2. Aboveground structures or elements flush with ground surface	35	Overpressure
3. Underground structural elements subjected to vertical pressure	65	Overpressure
4. Underground structural elements subjected to horizontal pressure	80	Overpressure
5. Openings in rock	50	Slant range

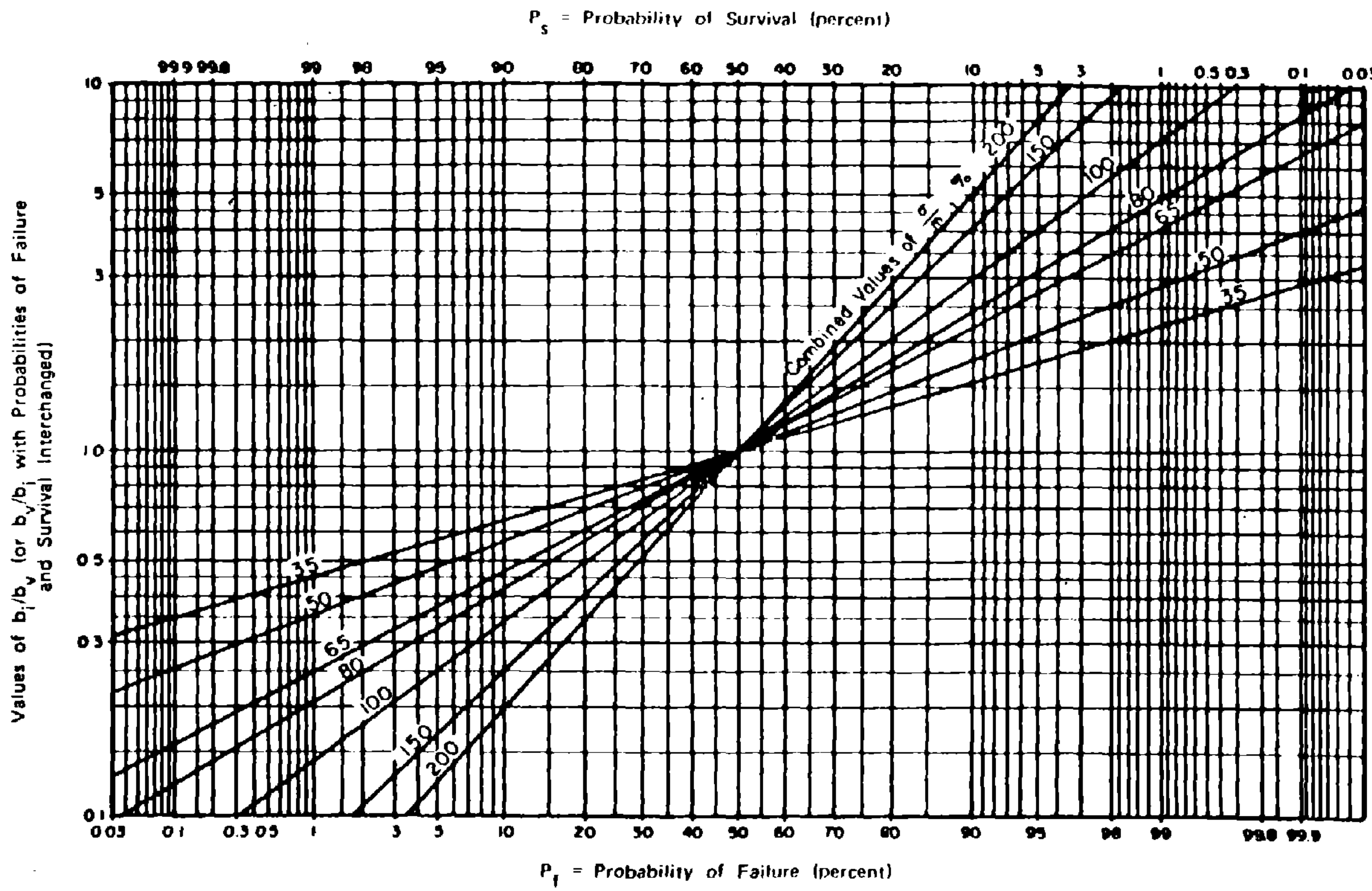

Figure C-1. [redacted] Probability Distributions for Failure or for Survival as Function of Ratio of Median Input Motion b_i to Median Vulnerability Level of Motion b_v [redacted]

[redacted]

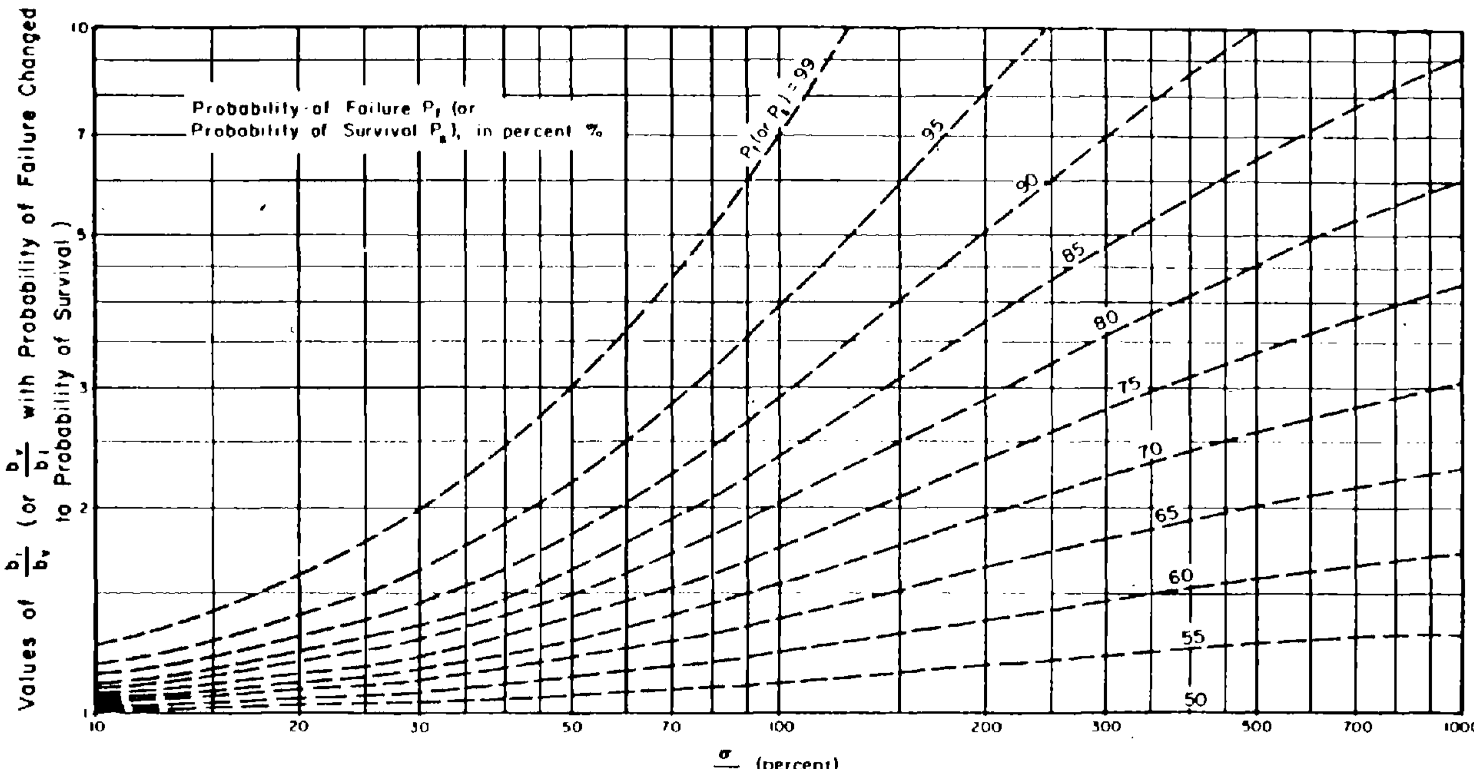

Figure C-2. [redacted] Coefficient of Variation σ/m as Function of b_i/b_v Ratio for Specified Probability of Failure (or of b_v/b_i for Specified Probability of Survival) [redacted]

[redacted]

[redacted] DAMAGE CAUSED BY PRESSURE [redacted]

C-5 Description of Charts for Damage to Surface Structures Caused by Pressure Input [redacted]

[redacted] The probability graphs presented in Figures C-1 and C-2 also apply to failure of surface structures that are sensitive to overpressures or dynamic pressures. In these cases, b_i is the median of the overpressure or dynamic pressure, and b_v is the median vulnerability to overpressure or dynamic pressure. Values of b_i, as a function yield, height of burst, and distance from ground zero may be obtained from the overpressure and dynamic pressure height of burst curves in Section I, Chapter 2.

[redacted] Tables C-2 and C-3 show the median values of overpressure and dynamic pressure respectively, b_v, that correspond to severe damage to the 22 types of structures for which isodamage curves are presented in Figure 11-2 through 11-23. The structures and the types of damage that are considered severe, moderate, or light for each structure are described by number in Table 11-1. Tables C-4 and C-5 show the corresponding overpressures and dynamic pressures, respectively, that provide moderate damage to the same family of structures. Even though the pressure required to produce a stated level of damage to a given structure with a given yield varies somewhat, as shown in the isodamage curves of Chapter 11, the median values presented in the tables are considered to be sufficiently reliable for the calculation of damage probabilities.

[redacted] The ratio σ_i/m_i for the input pressure is assumed to be 20 percent for both overpressure and dynamic pressures, and σ_v/m_v for pressure vulnerability is assigned a value of 30 percent. The combined value may be obtained from the equation given in paragraph C-3:

$$\sigma/m = \left\{\left(\frac{\sigma_i}{m_i}\right)^2 + \left(\frac{\sigma_v}{m_v}\right)^2 + \left(\frac{\sigma_i}{m_i}\right)^2 \left(\frac{\sigma_v}{m_v}\right)^2\right\}^{1/2},$$

$$\sigma/m = \left\{(0.2)^2 + (0.3)^2 + (0.2)^2 \quad (0.3)^2\right\}^{1/2},$$

$$\sigma/m \approx 35 \text{ percent.}$$

With this combined value of σ/m, the probability of failure of a given structure subjected to a specified overpressure or dynamic pressure from a known weapon yield can be determined from Figure C-1 or C-2. For example, consider a diffraction sensitive structure similar to type 11-3 that is subjected to an overpressure of 20 psi from a 3 kt explosion. From Table C-2, the median overpressure vulnerability corresponding to a 3 kt yield is 15 psi. The ratio b_i/b_v is, therefore, 1.333. Using b_i/b_v = 1.333, and σ/m = 35 percent, P_f = 80 percent as the probability of severe structural damage from either Figure C-1 or Figure C-2. The corresponding probability of failure for light to moderate damage of the same structure may be obtained similarly by using the appropriate overpressure vulnerability obtained from Table C-4.

[redacted] To design for a given probability of survival from severe damage from a specified overpressure or dynamic pressure, b_i, and weapon yield, W, enter Figure C-2 with the given P_s to obtain the value of b_v/b_i corresponding to σ/m = 35 percent. The structure should have a median vulnerability equal to the calculated b_v. For example, if the median overpressure from a 30 kt weapon is 10 psi, the design of a structure corresponding to structure type 11-5 with a 70 percent probability of survival from severe damage is determined from Figure C-2, with σ/m = 35 percent and P_s = 70 percent, to be b_v/b_i = 1.25. Hence, the structure must have a median vulnerability of 1.25 b_i = 12.5 psi to achieve a 70 percent probability of survival.

[redacted] To inflict severe damage to a surface structure of known type with a given probability of failure. Figure C-1 or C-2 is entered with this probability to obtain a ratio b_i/b_v corresponding to σ/m = 35 percent. The required median overpressure or dynamic pressure, b_i, is then obtained in terms of b_v from Table C-2 for diffraction sensitive structures or from Table C-3 for drag sensitive structures. A yield that will provide the required pressure input is then selected with the aid of the height of burst curves in Section I, Chapter 2.

C-6 Description of Charts for Damage to Underground Structures Caused by Pressure Input [redacted]

[redacted] Failure due to vertical overpressures or horizontal pressures must be distinguished for underground structures that are sensitive to soil pressures. Again, b_i is the median of the applied pressure. In this case, the median vulnerability, b_v, to vertical or horizontal pressure is obtained by the procedures discussed in Section II and III, Chapter 11.

[redacted] When using the probability charts, a value of σ/m = 65 percent should be used for structures and structural elements subjected to vertical pressures; however, for structures and structural elements subjected to horizontal pressures, a value of σ/m = 80 percent should be used with appropriate b_i/b_v or b_v/b_i. The procedure for the analysis of the probability of failure or of survival is the same as for aboveground structures. Therefore, the illustrations presented for aboveground structures may be followed.

[redacted] For deep underground openings in rocks that are sensitive to slant range, the quantities b_i and b_v must be expressed in terms of slant range. Similarly, the value of σ/m = 50 percent given in Table C-1 for openings also is expressed in the same term. The computation of probabilities of failure or of survival is again performed with Figure C-1 or Figure C-2. The procedure is the same as described above except that the ratio b_i/b_v or b_v/b_i is the ratio of the slant ranges, and a value of σ/m = 50 percent should be used (Table C-1).

C-7 Instructions for Pressure Input Analyses [redacted]

[redacted] The instructions given in paragraph C-3 pertaining to the use of Figures C-1 and C-2 for motion inputs also apply for pressure inputs. The only difference is in the determination of b_i/b_v and values of σ/m = 65 percent or 80 percent for underground structures sensitive to vertical and horizontal pressures, respectively or 35 percent for aboveground structures. In the case of pressure inputs, the pressure vulnerabilities of a structure are determined from one of the Tables C-2 through C-5 for aboveground structures. For underground structures, these vulnerabilities must be computed as described in Sections II and III of Chapter 11.

1. For a given surface structural type subjected to a specified weapon yield, determine the pressure vulnerability from Table C-2 or C-3 for severe damage, and from Table C-4 or C-5 for light to moderate damage. Tables C-2 and C-4 give the overpressure vulnerability for diffraction sensitive structures, while Tables C-3 and C-5 give the dynamic pressure vulnerabilities for drag sensitive structures. Comparable values for underground structures must be computed by the methods described in Chapter 11.

2. Using appropriate values of σ/m as given in Items 2, 3, and 4 of Table C-1 for aboveground and underground structures, the probabilities of failure or survival can be determined from Figure C-1 or Figure C-2.

C-8 Illustrative Examples for Pressure Inputs [redacted]

Example 1 [redacted]

[redacted] Consider a 5-story conventional reinforced concrete office building of the type de-

[redacted] scribed as Type 11-3 in Chapter 11. Assume that an explosion of 100 kt yield occurs at a height of burst of 1,100 ft. If the building is located at a distance of 4,200 ft from ground zero, the corresponding height of burst and ground distance from a 1 kt explosion would be

$$h_1 = \frac{h}{W^{1/3}} = \frac{1{,}100}{(100)^{1/3}} = 237 \text{ ft},$$

$$d_1 = \frac{d}{W^{1/3}} = \frac{4{,}200}{(100)^{1/3}} = 905 \text{ ft}.$$

From Figure 2-18, the overpressure is 15 psi. From Table C-2, the median vulnerability is 11 psi. Thus b_i/b_v = 15/11 = 1.36. With this value of b_i/b_v, and σ/m = 35 percent, the probability of severe damage is determined from Figure C-1 or Figure C-2 to be approximately 80 percent. To determine the probability of moderate damage, Table C-4 shows the median vulnerability to be 7 psi, and, therefore, b_i/b_v = 15/7 = 2.14. From Figure C-1 or Figure C-2, the probability of moderate damage is 98 percent.

Example 2 [redacted]

[redacted] For the same structure, yield, and height of burst that were used in Example 1, the distance corresponding to 20 percent probability of severe damage may be determined as follows. With σ/m = 35 percent and the probability of survival equal to (1-0.2) = 80 percent, Figure C-2 shows a ratio b_v/b_i = 1.35. Thus b_i = 11/1.35 = 8.15. The median overpressure, therefore, is 8.15 psi. From Figure 2-19, the distance from ground zero corresponding to a height of burst of 237 feet for a 1 kt explosion and 8.15 psi is 1,220 feet. The corresponding distance from a 100 kt explosion is 5,660 feet. The distance for 20 percent probability of moderate damage corresponds to an overpressure of 7/1.35 (Table C-3 and Figure C-2) = 5.18 psi. From Figure 2-19, the distance from ground zero corresponding to a height of burst of 237 feet for a 1 kt explosion and 5.18 psi is 1,650 feet. The corresponding distance from a 100 kt explosion is 7,660 feet.

C-9 System Consideration [redacted]

[redacted] The calculation of probabilities described in the preceding paragraphs pertains to the failure or survival of a single item or component. If the survival or proper performance of a complete piece of equipment or a system requires the survival of every component in the system, the components can be considered to be in series. An example is that of a shock mounted equipment; the satisfactory performance of the equipment requires the survival of the shock mount as well as of the equipment itself. In determining the failure probability or survival probability of a system the two points of view, the designer's and the weapon analyst's, must be distinguished in arriving at conservative estimates of the actual survival probabilities.

[redacted] From the designer's (defensive) point of view, a conservative estimate of the system failure probability is obtained if the failure of the components are assumed to be statistically independent. The probability of failure of the system is:

$$P_f = 1 - (1 - P_{f1})(1 - P_{f2}) \ldots (1 - P_{f(n-1)})(1 - P_{fn})$$

where $P_{f1}, P_{f2} \ldots P_{fn}$ are the probabilities of failure of the individual components, which can be determined with the procedure described in the preceding paragraphs.

[redacted] For example, in the case of the shock mounted equipment, if the probability of failure of the shock mount is 30 percent and that of the equipment is 40 percent, the probability of failure of the system is 1 - (0.70)(0.60) = 58 percent.

Table C-2. [redacted] Median Vulnerability to Overpressures Corresponding to Severe Damage of Diffraction Sensitive Structures [redacted]

Weapon Yield	Type of Structure				
	11-2	11-3	11-4	11-5	11-6
	(Median Vulnerability Overpressure, psi)				
30 mt	28	10	5.0	9.0	3.4
10 mt	29	10	5.0	9.0	3.4
3 mt	30	10	5.0	9.0	3.4
1 mt	30	11	5.0	9.0	3.5
300 kt	30	11	5.0	9.0	3.5
100 kt	32	11	5.0	9.5	3.5
30 kt	34	12	5.0	9.5	3.6
10 kt	34	13	5.5	10.0	3.6
3 kt	36	15	5.5	10.0	3.8
1 kt	48	17	5.5	11.0	4.0
[illegible]	–	20	6.0	12.0	4.4
0.1 kt	–	22	6.5	12.0	4.8
0.03 kt	–	24	7.0	13.0	5.2
0.01 kt	–	28	7.5	14.0	5.8

Table C-3. [redacted] Median Vulnerability to Dynamic Pressures Corresponding to Severe Damage of Drag Sensitive Structures [redacted]

Weapon Yield	Type of Structure																
	11-7	11-8	11-9	11-10	11-11	11-12	11-13	11-14	11-15	11-16	11-17	11-18	11-19	11-20	11-21	11-22	11-23
	(Median Vulnerability of Dynamic Pressure, psi)																
30 mt	0.8	1.6	2.6	5.0	2.4	5.0	2.6	2.4	2.0	2.0	9.6	5.0	2.8	3.3	2.0	1.4	0.6
10 mt	0.8	1.6	2.6	6.0	2.6	5.0	2.8	2.4	2.0	2.0	10.0	5.0	2.8	3.3	2.0	1.4	0.6
3 mt	0.9	1.8	2.8	7.0	3.0	6.0	3.0	2.6	2.0	2.0	13.0	5.2	2.8	3.3	2.0	1.4	1.0
1 mt	1.0	2.0	3.2	8.5	3.6	7.0	3.4	3.0	2.0	2.0	20.0	6.0	2.8	3.4	2.0	1.4	1.6
300 kt	1.2	2.2	3.6	12.0	4.8	9.0	4.2	3.8	2.5	2.0	48.0	8.0	3.0	4.0	2.0	1.4	2.8
100 kt	1.4	2.6	4.4	18.0	6.0	11.0	5.2	5.0	3.0	2.2		12.0	3.4	5.2	2.2	1.4	4.5
30 kt	2.0	3.6	5.8	34.0	10.0	16.0	7.0	10.0	4.0	2.6	—	20.0	4.0	10.0	2.6	1.4	7.5
10 kt	3.2	5.2	7.5	—	16.0	26.0	10.0	24.0	7.0	3.5		40.0	5.2	24.0	3.4	1.6	12.0
3 kt	5.4	7.5	12.0	—	36.0	—	18.0		15.0	5.0		—	7.0		4.6	2.0	20.0
1 kt	9.5	13.0	20.0	—	60.0		28.0	—	35.0	12.0	—	—	12.0	—	8.0	2.2	32.0
0.3 kt	18.0	26.0	38.0	—	—	—							22.0	—	18.0	3.0	55.0
0.1 kt	—	—	—	—	—	—	—	—	—		—	—	—	—		4.0	85.0
0.03 kt	—	—	—	—	—		—	—		—			—	—	—	6.0	
0.01 kt	—	—	—	—		—	—	—		—	—		—	—	—	9.0	—

[redacted]

Table C-4. [redacted] Median Vulnerability to Overpressures Corresponding to Moderate Damage of Diffraction Sensitive Structures [redacted]

Weapon Yield	Type of Structure				
	11-2	11-3	11-4	11-5	11-6
	(Median Vulnerability Overpressure, psi)				
30 mt	20	6.5	3.4	6.5	2.2
10 mt	20	6.5	3.4	6.5	2.2
3 mt	20	6.5	3.4	6.5	2.2
1 mt	20	6.5	3.4	6.5	2.2
300 kt	20	6.5	3.4	6.5	2.2
100 kt	20	7.0	3.4	6.5	2.2
30 kt	20	7.0	3.4	6.5	2.2
10 kt	20	7.0	3.6	6.5	2.2
3 kt	22	7.5	3.6	6.5	2.2
1 kt	24	8.0	3.6	6.5	2.2
0.3 kt	28	9.0	3.8	7.0	2.4
0.1 kt	–	10.0	4.0	7.5	2.6
0.03 kt	–	11.0	4.2	7.5	2.8
0.01 kt	–	12.0	4.4	8.0	3.0

[redacted]

Table C-5. [redacted] Median Vulnerability to Dynamic Pressures Corresponding to Moderate Damage of Drag Sensitive Structures [redacted]

Weapon Yield	Type of Structure																
	11-7	11-8	11-9	11-10	11-11	11-12	11-13	11-14	11-15	11-16	11-17	11-18	11-19	11-20	11-21	11-22	11-23
	(Median Vulnerability of Dynamic Pressure, psi)																
30 mt	0.6	1.2	2.0	3.4	1.6	3.6	2.0	2.4	2.0	2.0	9.6	5.0	2.8	3.2	2.0	1.4	0.2
10 mt	0.6	1.2	2.0	3.4	1.6	3.6	2.0	2.4	2.0	2.0	10.6	5.0	2.8	3.2	2.0	1.4	0.2
3 mt	0.6	1.2	2.0	3.4	1.6	3.6	2.0	2.4	2.0	2.0	12.0	5.2	2.8	3.2	2.0	1.4	0.4
1 mt	0.6	1.2	2.0	3.6	1.8	3.8	2.0	2.6	2.0	2.0	16.0	5.8	2.8	3.2	2.0	1.4	0.6
300 kt	0.6	1.2	2.0	4.0	2.0	4.0	2.2	2.8	2.0	2.0	26.0	7.4	2.8	3.4	2.0	1.4	1.0
100 kt	0.6	1.2	2.2	4.4	2.0	4.4	2.4	3.2	2.2	2.0	46.0	9.0	3.0	4.0	2.0	1.4	2.0
30 kt	0.6	1.4	2.4	5.4	2.4	5.2	2.6	4.0	2.8	2.2	88.0	14.0	3.4	5.0	2.2	1.4	3.0
10 kt	0.8	1.4	2.6	7.5	3.0	6.0	3.0	6.0	3.6	2.8	–	22.0	4.0	8.4	2.4	1.4	5.0
3 kt	0.8	1.6	3.2	12.0	4.4	9.0	3.6	12.0	6.4	4.2	–	40.0	5.4	18.0	3.4	1.6	8.0
1 kt	1.0	2.0	4.0	20.0	7.5	12.0	5.0	30.0	12.0	6.2	–	–	7.4	36.0	4.6	1.8	13.0
0.3 kt	1.2	3.0	6.0	40.0	13.0	22.0	9.0	–	–	16.0	–	–	10.0	–	6.4	2.2	22.0
0.1 kt	2.2	5.0	10.0	–	20.0	–	16.0	–	–	–	–	–	15.0	–	14.0	2.6	60.0
0.03 kt	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.4	100.0
0.01 kt	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4.2	–

[redacted] However, from the weapon analyst's (offensive) standpoint, a conservative estimate of the system failure probability may be obtained if the failure or survival of the components are assumed to be perfectly correlated. In this case, the probability of failure of the system is equal to the largest value among the failure probabilities of the components, or

$$P_f = \max\,(P_{f1}, P_{f2}, \ldots, P_{fn})\,.$$

In the example given above for shock mounted equipment, the system failure probability would be 40 percent.

SECTION II

[redacted] DERIVATION OF EQUATIONS USED IN SECTION I [redacted]

[redacted] The treatment used herein is based on the logarithmic normal distribution that was used in Section I. Values were given for the ratio of the standard deviation to the mean of a lognormal distribution, obtained by combining the corresponding quantities for individual parameters governing the distribution.

[redacted] Consider a logarithmic normal distribution for vulnerability, characterized by the parameter σ_v for standard deviation, m_v for mean, b_v for median. Now consider also a logarithmic normal distribution for input having similar parameters, but with the subscript i instead of v. Each case is designated by α_v and β_v or α_i and β_i, respectively, the mean value and standard deviation of the logarithm of the corresponding variate.

C-10 Properties of Lognormal Variates [redacted]

[redacted] For logarithmic normal random variables, the relationships between the above parameters are as follows:

$$m = e^{\alpha + \frac{\beta^2}{2}}\,,$$

$$\sigma^2 = m^2\left(e^{\beta^2} - 1\right), \quad \text{or} \quad \left(\frac{\sigma}{m}\right)^2 = e^{\beta^2} - 1.$$

Thus,

$$\beta^2 = \ln\left[\left(\frac{\sigma}{m}\right)^2 + 1\right]$$

Also,

$$\alpha = \ln\, b$$

where b is the median of the lognormal variable.

C-11 Probability of Failure or Survival [redacted]

[redacted] Assume that the input I and vulnerability V are both logarithmic normal variates with mean and standard deviations m_i, σ_i and m_v, σ_v, respectively, and hence corresponding medians b_i and b_v. The logarithms of the input and vulnerability are therefore individually normal random variables.

[redacted] Failure occurs whenever the vulnerability is less than or equal to the input: or $I/V \geqslant 1.0$. If

$$X = \frac{I}{V},$$

then failure means $X \geqslant 1.0$, or $\ln X = (\ln I - \ln V) \geqslant 0$. Therefore, $\ln X$ is also normal with parameters

$$\alpha = \alpha_i - \alpha_v,$$

and

$$\beta = \left(\beta_v^2 + \beta_i^2\right)^{1/2}.$$

Therefore, the probability of failure P_f is

$$P_f = \frac{1}{\sqrt{2\pi}\,\beta}\int_0^\infty e^{-\frac{1}{2}\left(\frac{\ln X - \alpha}{\beta}\right)^2}\, d(\ln X).$$

[redacted]

Let

$$y = \frac{\ln X - \alpha}{\beta}.$$

Then

$$dy = \frac{d(\ln X)}{\beta},$$

and

$$P_f = \frac{1}{\sqrt{2\pi}} \int_{-\frac{\alpha}{\beta}}^{\infty} e^{-\frac{1}{2}y^2} \, dy$$

= area of standard normal curve from $-\frac{\alpha}{\beta}$ to ∞.

But

$$\alpha = \alpha_i - \alpha_v = \ln b_i - \ln b_v.$$

Hence,

$$\alpha = \ln \frac{b_i}{b_v},$$

and,

$$\beta = \left(\ln\left[\left(\frac{\sigma}{m}\right)^2 + 1\right]\right)^{1/2} = \left(\beta_v^2 + \beta_i^2\right)^{1/2}.$$

Therefore,

$$\ln\left[\left(\frac{\sigma}{m}\right)^2 + 1\right] = \ln\left[\left(\frac{\sigma_v}{m_v}\right)^2 + 1\right]\left[\left(\frac{\sigma_i}{m_i}\right)^2 + 1\right],$$

and

$$\left(\frac{\sigma}{m}\right) = \left(\left(\frac{\sigma_v}{m_v}\right)^2 + \left(\frac{\sigma_i}{m_i}\right)^2 + \left(\frac{\sigma_v}{m_v}\right)^2\left(\frac{\sigma_i}{m_i}\right)^2\right)^{1/2}.$$

This is the equation given in paragraph C-3. Therefore, for specified (σ/m), β is a non-negative constant, and

$$P_f = \frac{1}{\sqrt{2\pi}} \int_{-\frac{\alpha}{\beta}}^{\infty} e^{-\frac{1}{2}y^2} \, dy$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\frac{1}{\beta}\ln\left(\frac{b_i}{b_v}\right)}^{\infty} e^{-\frac{1}{2}y^2} \, dy.$$

which gives a linear plot of b_i/b_v with P_f on lognormal probability paper, as shown in Figure C-1.

[redacted] If the ordinates in Figures C-1 and C-2 are expressed in b_v/b_i, it can be shown that the probability of failure in these curves becomes the probability of survival. From the equations given above,

$$P_s = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\frac{1}{\beta}\ln\left(\frac{b_i}{b_v}\right)}^{\infty} e^{-\frac{1}{2}y^2} \, dy$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{1}{2}y^2} \, dy -$$

[redacted]

$$\frac{1}{\sqrt{2\pi}} \int_{-\frac{1}{\beta} \ln\left(\frac{b_i}{b_v}\right)}^{\infty} e^{-\frac{1}{2} y^2}\, dy$$

$$= \int_{-\infty}^{-\frac{1}{\beta} \ln\left(\frac{b_i}{b_v}\right)} e^{-\frac{1}{2} y^2}\, dy$$

$$= \int_{-\infty}^{\frac{1}{\beta} \ln\left(\frac{b_v}{b_i}\right)} e^{-\frac{1}{2} y^2}\, dy.$$

Since the standard normal distribution is symmetric about the origin, this integral is equal to the integral for P_f. Therefore, the probabilities in Figures C-1 and C-2 become probabilities of survival if the ordinates are replaced by b_v/b_i.

APPENDIX D

[redacted] ABSTRACTS OF DNA HANDBOOKS [redacted]

[redacted] NUCLEAR WEAPONS BLAST PHENOMENA [redacted]

[redacted] *DASA 1200 (Vols. I-V)* (Vol. I, SRD; Vol. II, CRD; Vol. III, SFRD; Vol. IV, to be published; Vol. V, CFRD).

[redacted] *Prepared by:* DASIAC, Santa Barbara, California. Major contributors: Defense Atomic Support Agency, Kaman Nuclear, URS Research Company, Bolt, Beranek, and Newman, and Dikewood Corporation.

[redacted] *Availability:* Volumes I through III through Defense Documentation Center on request through Defense Nuclear Agency, Washington, D.C. 20305. Volume V, limited distribution.

[redacted] DASA 1200 is a source book of air blast data and theory applicable to nuclear explosions occurring in free air, on or near the surface, and beneath the surface. Volume I begins with a detailed description of the nuclear explosion energy source, and presents the theoretical background associated with the formation and propagation of the blast wave in free air. The long range propagation of shock waves is treated in detail. Volume II presents a discussion of blast wave interaction phenomena, including ideal reflection and refraction, ideal diffraction, and nonideal effects. A discussion of topography and shock wave shielding and a section on air blast measurements in the high pressure region also are included. Volume III contains an analysis of and methods for the prediction of the blast phenomena from nuclear weapons burst at moderate altitudes, on the surface, underwater, and underground. Volume IV contains a discussion of the simulation of nuclear air blast phenomena with high explosives. Volume V is a compilation of the measurements of the various blast parameters associated with nuclear weapons at the various nuclear operations. It is planned for limited distribution to scientists and agencies who are working in the field of nuclear weapons blast phenomena.

[redacted] HANDBOOK OF UNDERWATER NUCLEAR EXPLOSIONS [redacted]

DASA 1240 [redacted]

[redacted] *Prepared by:* DASIAC, Santa Barbara, California. Major contributors include NOL, DTMB, Waterways Experiment Station, Naval Civil Engineering Laboratory and the U.S. Naval Radiological Defense Laboratory.

[redacted] *Availability:* Qualified requestors may obtain these documents from the Defense Documentation Center. Each transmittal outside the agencies of the U.S. Government must have prior approval of the Defense Nuclear Agency.

[redacted] The Handbook of Underwater Nuclear Explosions is divided into two parts: Part I, Phenomena, consists of 11 chapters, and Part II, Effects, consists of 13 chapters. Individual chapters and in some cases sections of chapters have been previously published separately.

[redacted] The entire handbook is undergoing revision and will be published in three volumes. The revised Handbook of Underwater Nuclear Explosions will be an authoritative presentation of current knowledge and a reliable source of useful data concerning the phenomena of underwater nuclear explosions. The presentation will include the phenomena of shock wave propaga-

[redacted] tion, surface waves, underwater cratering, and radioactive debris. The effects of underwater explosions on surface ships, submarines, harbors, and structural installations also will be described.

[redacted] NUCLEAR GEOPLOSICS (A Sourcebook of Underground Phenomena and Effects of Nuclear Explosions [redacted]

[redacted] *DASA 1285 (Volumes I-V)* [redacted]

[redacted] *Prepared by:* Stanford Research Institute, Menlo Park, California.

[redacted] *Availability:* This document is not approved for open publication or distribution to the Office of Technical Services, Department of Commerce. Qualified requestors may obtain copies of this report from Defense Documentation Center. Foreign announcement and dissemination of this report is not authorized. [redacted]

[redacted] The Nuclear Geoplosics Handbook contains five volumes: Part I, Theory of Directly Induced Ground Motions; Part II, Mechanical Properties of Earth Materials; Part III, Test Sites and Instrumentation; Part IV, Empirical Analysis of Ground Motion and Cratering; and Part V, Effects on Underground Structures and Equipment.

[redacted] The theory of directly induced ground motion is presented in Part I. The tools and elements required for the study of ground motion effects are discussed. Two analytical solutions of shock propagations are presented. Theoretical predictions (obtained by numerical and analytical methods) are compared with field measurements. The mechanical properties of earth materials are described in Part II. It consists of a preparation of a clear and systematic, but largely qualitative, description of the resistance of earth materials to compression and shear. A summary on stress-strain behavior with very short load durations is included. The basic concepts regarding the mechanical behavior of soil and experimental methods of determining the mechanical properties of soil are described. The physical characteristics of test sites and instrumentation of nuclear and high explosive detonations on which ground motion has been measured are presented in Part III. The discussion of air blast induced ground motion in Part IV relies primarily on experimental evidence. A knowledge of the effects induced in the free field ground motion, the factors influencing these effects, the structure-medium interaction, and the factors influencing interaction is implicit in the study of behavior of underground structures. Part V summarizes these various phenomena as they apply to understanding structures in general and discusses the behavior of equipment mounted within a structure.

[redacted] The book is meant to be an authoritative sourcebook. It is not meant to be a handbook of design specifications.

[redacted] Part II and Part IV are currently under revision. Publication is expected during calendar year 1973.

[redacted] TREE (Transient-Radiation Effects on Electronics) HANDBOOK [redacted]

[redacted] DNA 1420 H-1 (edition 3), DNA 1420 H-2 (edition 3), (1420 H-1, [redacted] 1420 H-2, [redacted]

[redacted] *Prepared by:* Battelle Memorial Institute, Columbus, Ohio

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center. Foreign announcement and dissemination is not authorized.

[redacted] The TREE Handbook consists of two volumes which present information that will be useful to a design engineer who is designing electronic systems for survival in a nuclear-burst environment. The information that is presented covers those areas directly related to electronic parts, circuits, and systems. The

[redacted]

nuclear-burst environment that is covered includes both transient and steady state. It also includes all radiation effects except external EMP. Major areas covered in DNA 1420 H-1 are: the simulated versus burst environment, interaction of transient radiation with matter, discrete semiconductor devices, integrated circuits, capacitors, resistors, miscellaneous electronic materials and devices, circuit hardening, and network analysis techniques. DNA 1420 H-2 discusses the nuclear weapon-burst environment, interaction of transient radiation with matter, system hardening, and internal EMP.

[redacted] The TREE Handbook is updated on a continuing basis.

[redacted] THEORETICAL MODELS FOR NUCLEAR FIREBALLS [redacted]

[redacted] *DASA 1589-A, 1589-B, 1589-1 through 1589-39* (1589-A, [redacted] 1589-B, [redacted] 1589-1 through 1589-39, [redacted]

[redacted] *Prepared by:* Lockheed Missiles and Space Company, Sunnyvale, California.

[redacted] The first volume, with parts A and B, describes a radiation hydrodynamic code appropriate for calculation of nuclear fireball phenomenology in the lower atmosphere. Part A describes the code, and part B discusses the results. The FIREBALL code is a one dimensional, spherical, Lagrangian, radiation-hydrodynamics code, which employs a non-grey transport equation to describe the radiation field. The code is used to compute 39 theoretical models for bombs of various explosion yields at various altitudes. These graphical descriptions are the 39 volumes (DASA 1589-1 through 1589-39). Results are compared to experimental measurements made in U.S. field tests.

[redacted] WEAPONS RADIATION SHIELDING HANDBOOK [redacted]

[redacted] *DASA 1892-1 through 1892-6* (DASA 1892-1, -2, -3, and -5 [redacted] DASA 1892-4, [redacted] DASA 1892-6, [redacted]

[redacted] *Prepared by:* Oak Ridge National Laboratory, Oak Ridge, Tennessee. Major contributors: Radiation Research Associates and the University of Tennessee.

[redacted] *Availability:* Qualified requestors may obtain these documents from the Defense Documentation Center. Requests for DASA 1892-4 must be on request through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] DASA 1892-5 (Chapter 2 of the handbook) describes the basic concepts underlying the methods used for weapon radiation shield analyses. These concepts include the quantities used to describe particle populations and the quantities used to describe radiation interactions with materials. The characteristics of the particular radiations produced by weapons, neutrons and gamma rays, are discussed in detail, including their physical properties and their important interactions. The processes by which neutrons and gamma rays are produced also are described. The chapter also discusses the various response functions that are used to convert a radiation field to a biological effect.

[redacted] DASA 1892-3 (Chapter 3 of the handbook) surveys the methods used most frequently to calculate the attenuation of neutrons and gamma rays. Summaries of computer codes based on the various methods also are provided. All of the techniques are either approximate solutions to the Boltzmann equation or are based on kernels obtained from solutions to the equation.

[redacted] DASA 1892-2 (Chapter 4 of the handbook) surveys the work performed to date on [redacted] the various types of nuclear radiation albedos, particularly as they relate to penetration of air filled openings through radiation shields (ducts, passageways, etc.). This topic is important in that the primary increase in the radiation that penetrates a shield results from such openings and enters primarily as a result of the successive scattering of the radiation from the walls of the openings. Most of the techniques for estimating the transmission through such openings depend on the use of albedos.

[redacted] DASA 1892-1 (Chapter 5 of the handbook) describes effective methods for designing air filled holes in protective structures (access ways, ventillation ducts, other utility pipes, distributed voids resulting from the use of nonhomogeneous material in the structure, etc.) to reduce the amount of radiation that enters the structure.

[redacted] DASA 1892-4 (Chapter 6 of the handbook) describes the various sources of radiation produced by a nuclear explosion and presents techniques for calculating the transport of the radiations from the point of burst to the surface of a shield, i.e., it presents methods for determining source terms for shield attenuation calculations. The emphasis is on initial radiation, i.e., that produced within the first minute following the explosion.

[redacted] DASA 1892-6 (Chapter 7 of the handbook) presents a simplified method for designing (or evaluating) shield covers on single compartment underground structures that will protect against the neutrons and initial gamma rays. Emphasis is given to neutrons. The method is limited to surface or near surface bursts, to weapon yields between 1 kiloton and 20 megatons, and to distances from the burst at which overpressures are between 5 and 100 psi, but no closer than 500 meters.

[redacted] THERMAL RADIATION PHENOMENA [redacted]

[redacted] *DASA 1917 (Volumes 1-6)* (Vols. I-V, [redacted] Vol. VI, [redacted]

[redacted] *Prepared by:* Lockheed Missiles and Space Company, Palo Alto Research Laboratory, Palo Alto, California. Major contributor: The Rand Corporation.

[redacted] *Availability:* Qualified requestors may obtain these documents from the Defense Documentation Center. Volumes I through V are approved for open publication. Volume VI is available only by request through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] Volume I of the six volume handbook describes the equilibrium thermodynamic properties of high temperature air. The report contains information on air and a mixture of ideal gases in chemical equilibrium: ideal gas properties for monatomic gases, diatomic gases, and polyatomic gases. The effects of interparticle forces on the thermodynamic properties of air, effects of coulomb forces on the thermodynamic properties of air, and equilibrium calculations and results for air are discussed. Tables and graphs of the composition and properties of the atmosphere are included.

[redacted] Volume II presents the theoretical aspects of the equilibrium radiative properties of air. The theory of radiation in hot gases (elementary radiative transfer, theory of radiation, theory of molecular absorption) is described. Spectral and mean absorption coefficients of heated air and spectroscopic properties of six important band systems that contribute to opacity of heated air are included.

[redacted] Tables of the equilibrium radiative properties of air and its constituents are presented in Volume III for a wide range of temperatures and densities. The information contained in the tables is a combination of experimental data and theoretical computation.

[redacted] Volume IV describes the excitation and nonequilibrium phenomena of air that has been subjected to a large amount of radiation. Topics include: absorption and scattering of X-rays and gamma rays; collisions of ions and electrons with air molecules; secondary processes following this excitation (including the creation of various chemical species); X-ray heating and shock heating of air, with special reference to very high energy densities; the approach to composition equilibrium in low and high temperature air; adiabatic, near equilibrium cooling of air and the formulation of a criterion for local thermodynamic equilibrium; nonequilibrium radiative transport and its effect on the total amount and the spectrum of emitted radiation; radiation in tenuous air at high temperatures; and radiation in tenuous air with contaminants at low temperatures.

[redacted] Volume V provides an introduction to radiation hydrodynamics (RH). It contains a discussion of the application of RH to fireballs in the atmosphere. After formulating the basic equations of RH, special attention is given to the radiative transfer problem. Several methods for solving the equations of transfer are touched upon, but special emphasis is placed on the two stream method with a frequency averaging procedure, which is specifically designed for use with finite zone sizes. A version of the fireball code, which uses this approach, is described.

[redacted] Volume VI provides data concerning the interaction of nuclear weapon radiation and debris with the atmosphere. The theoretical analysis of fireball development uses computations based on the equations of radiation hydrodynamics (RH). Various models for simplifying these equations are described, and a summary of codes and calculations based on these models is included. The emphasis of the theoretical discussion is on the status of understanding rather than a detailed quantitative treatment. Yield and altitude scaling laws are developed.

[redacted] DASA REACTION RATE HANDBOOK

DNA 1948H [redacted]

Prepared by: General Electric Company, Missile and Space Division, Philadelphia, Pennsylvania. Major contributors: General Electric, TEMPO, University of Pittsburgh, Air Force Cambridge Laboratory, Geophysics Corporation of America, The Rand Corporation, G. C. Dewey Corporation, University of Colorado, General Atomic, Westinghouse Research Laboratories, NASA Ames Research Center, and Air Force Weapons Laboratory.

[redacted] *Availability:* Qualified requestors may obtain this handbook from the Defense Documentation Center.

[redacted] This handbook contains useful, accurate, and reliable information on upper atmospheric chemical and physical processes. Such information is required for the solution of various problems involving military radar and communication blackout. Periodic additions to, and revisions of, this handbook are planned to accomodate new information, revisions of older data, corrections, etc. The material is presented in 19 separate chapters covering pertinent aspects of reaction rate science. Appropriate appendices and illustrations are included.

[redacted] This handbook was issued in March 1973 and is still in process of being completed according to original plans. Several revisions have been made to update the original contents.

[redacted] NUCLEAR EFFECTS ON VLF AND LF COMMUNICATION SYSTEMS [redacted]

[redacted] *DASA 1954 (Volumes I and II)* (Vol. I, [redacted] Vol. II, [redacted]

[redacted] *Prepared by:* Institute for Telecommunications Sciences, Boulder, Colorado. Major contributors: General Electric/TEMPO, Illinois Institute of Technology Research Institute.

[redacted] *Availability:* Qualified requestors may obtain these documents from the Defense Documentation Center through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] This handbook is published in two volumes that describe the effects of nuclear bursts on the propagation of LF and VLF communication systems.

[redacted] The examples presented in Volume I illustrate the approximate duration and extent over which typical systems may experience difficulty. In addition to specific results, a brief tutorial description of the effects of nuclear bursts on radio wave propagation and VLF and LF propagation in natural environments is given.

[redacted] Volume II presents techniques for modeling a relatively wide range of nuclear situations and for predicting how these situations would degrade LF and VLF communications system performance. This volume is intended to be used with Volume I. Together, they provide a basic understanding of nuclear phenomenology and its interrelation with LF and VLF propagation.

[redacted] NUCLEAR EFFECTS ON HF COMMUNICATION SYSTEMS [redacted]

[redacted] *DASA 1955 (Volumes I and II)* [redacted]

[redacted] *Prepared by:* Stanford Research Institute, Menlo Park, California. Major contributors: General Electric/TEMPO, Illinois Institute of Technology Research Institute.

[redacted] *Availability:* Qualified requestors may obtain these documents from the Defense Documentation Center through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] This handbook is published in two volumes that describe propagation effects of nuclear bursts on HF communication systems.

[redacted] The examples presented in Volume I illustrate the approximate duration and extent over which typical systems may experience difficulty. In addition to specific results, a brief tutorial description of the effects of nuclear bursts on radio wave propagation and HF propagation in natural environments is given.

[redacted] Volume II presents techniques for modeling a relatively wide range of nuclear situations and for predicting how these situations would degrade HF communication system performance. This volume is intended to be used with Volume I. Together they provide a basic understanding of nuclear phenomenology and its interrelation with HF propagation.

[redacted] NUCLEAR EFFECTS ON SATELLITE AND SCATTER COMMUNICATION SYSTEMS [redacted]

[redacted] *DASA 1956-1, 1956-2 Vol. I, 1956-2 Vol. II* [redacted]

[redacted] Electromagnetic Systems Laboratories, Sunnyvale, California. Major contributors: General Electric/TEMPO, Illinois Institute of Technology Research Institute.

[redacted] *Availability:* Qualified requestors may obtain these documents from the Defense Documentation Center through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] This handbook contains two parts. Part 1 describes the propagation effects of selected nuclear bursts on satellite and scatter communication systems. The examples presented illustrate the approximate duration and extent over which typical systems may experience difficulty. In addition to specific results, a brief tutorial description of the effects of nuclear bursts on radio wave propagation and satellite and scatter propagation in natural environments is given.

[redacted] Part 2, consisting of two volumes, describes the effects of nuclear bursts on the propagation of satellite communication systems

[redacted]

(Vol. I) and troposcatter and ionoscatter communication systems (Vol. II). Techniques to model a relatively wide range of nuclear situations and to predict how these situations would degrade the communication systems performance are presented. These volumes are intended to be used with DASA 1956-1. Together, they provide a basic understanding of nuclear phenomenology and its interrelation with propagation to satellites.

[redacted] TREE PREFERRED PROCEDURES (Selected Electronic Parts) [redacted]

[redacted] *DNA 2028H* [redacted]

[redacted] *Prepared by:* Battelle Columbus Laboratories, Columbus, Ohio.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center.

[redacted] This document provides persons conducting TREE (transient radiation effects on electronics) experiments with recommended procedures which experience has shown to be efficient for determining transient radiation effects on electronic parts. Areas that are covered in detail include: experimental design, experimental documentation, dosimetry and environmental correlation, and preferred measurement procedures for diodes, transistors, capacitors, and microcircuits.

[redacted] HANDBOOK FOR ANALYSIS OF NUCLEAR WEAPON EFFECTS ON AIRCRAFT [redacted]

[redacted] DNA 2048 (Revised March 1976) (DNA 2048 H-[redacted] DNA 2048 H-2. [redacted]

[redacted] *Prepared by:* Kaman Avidyne, Burlington, Massachusetts

[redacted] *Availability:* Qualified requestors may obtain this handbook from the Defense Documentation Center.

[redacted] This handbook and its supplement are designed for use in analyzing conventional nuclear weapon effects on aircraft. DNA 2048 contains a comprehensive review of a large body of available literature pertinent to vulnerability and safety analysis of aircraft subjected to the effects of nuclear explosions. The handbook describes methods for analyzing material velocity, overpressure, thermal radiation and nuclear radiation effects on airplanes and helicopters, including the crew. Sure-safe and sure-kill criteria pertinent to the various weapon effects are presented, as well as the methods to be employed in constructing aircraft sure-safe and sure-kill burst-time volumes. The supplement to DNA 2048 is a handbook of computer programs designed to analyze nuclear weapon effects on aircraft. Detailed methodology for anlyzing material velocity (gust), overpressure, thermal radiation and nuclear radiation effects on airplanes and helicopters, including crew, are presented. Only the computer programs corresponding to the methods of analyzing of DNA 2048 are included, and a full understanding of the programs will require access to DNA 2048.

[redacted] A MANAGEMENT GUIDE TO TREE [redacted]

DNA 2051H [redacted]

[redacted] *Prepared by:* Batelle Columbus Laboratories, Columbus, Ohio.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] This guide is intended primarily for management personnel associated with the development of electronic systems that must survive the transient radiation environment generated by a nuclear explosion. The document is intended to be useful to the manager, whether his background and responsibilities are wholly technical, technically oriented, or wholly administrative. The guide is also a satisfactory primer for engineering and scientific personnel.

[redacted] SUMMARY OF COMMUNICATION SYSTEMS DEGRADATION IN A NUCLEAR ENVIRONMENT [redacted]

[redacted] *DASA 2090* [redacted]

[redacted] *Prepared by:* General Electric/TEMPO, Santa Barbara, California. Major contributor: Illinois Institute of Technology Research Institute.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] This report summarizes the degradation of communication systems in a nuclear environment. It is based on the results of a three year program to determine the effects of nuclear detonations on communication systems. The report provides information that will aid in determining whether sophisticated analyses are required to predict degradation.

[redacted] DNA EMP (ELECTROMAGNETIC PULSE) HANDBOOK [redacted]

[redacted] *DNA 2114H-1 (Volume 1), DNA 2114H-2 (Volume 2), DNA 2114H-3 (Volume 3), DNA 2114H-4 (Volume 4),* (Volumes 1, 2, and 4 [redacted]. Volume 3, [redacted] Volume 3 will be issued early in calendar year 1973.

[redacted] *Prepared by:* DASIAC, Santa Barbara, California. Major contributors: Illinois Institute of Technology Research Institute, Mission Research Corporation, American Nucleonics Corporation, Lawrence Livermore Laboratory, U.S. Army Harry Diamond Laboratories, Braddock, Dunn and McDonald, Incorporated, Hughes Aircraft Corporation, Procedyne Corporation, Stanford Research Institute, Sandia Corporation, Air Force Weapons Laboratory, Massachusetts Institute of Technology, Defense Nuclear Agency, General Electric/TEMPO.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center. Volume 3 must be obtained on request through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] Volume 1 is designed for the practical electrical engineer. It contains information concerning an overall system evaluation and the practices that should be followed in circuit layout, shielding, grounding, and the use of protective devices for systems that are hardened to EMP. Volume 2 is designed for the theoretical or experimental analyst. It includes an analytic treatment of EMP problems in shielding, antennas, cables, and filters, experimental and analytic information on component degradation, and survey information on test methods and hardware. Volume 3 develops EMP threat criteria and provides an assessment of real system effects. The EMP environment information is presented from a system standpoint. Volume IV contains bibliographic and computer code information. Over 1,000 citations are given for such topics as theoretical calculations and nuclear test data related to the EMP environment and detection, EMP vulnerability analysis for systems and components, EMP protection, internal EMP, test direction and planning, and EMP simulators, sensors, and instrumentation. Current EMP computer codes are described and compared for the topics of environment, internal EMP, and circuit analysis.

[redacted] CORRECTIONS FOR DASA COMMUNICATION HANDBOOK (DASA 1954, 1955, 1956) [redacted]

[redacted] *DASA 2313* [redacted]

[redacted] *Prepared by:* General Electric/TEMPO, Santa Barbara, California.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center. No foreign dissemination is allowed without approval of Headquarters.

[redacted]

[redacted]

Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] This handbook provides a set of corrections to the DASA Communications Handbooks, DASA 1954, 1955 and 1956 (see abstracts of these handbooks above).

[redacted] TREE SIMULATION FACILITI[redacted]

[redacted] DNA 2432H (Edition 1) [redacted]

[redacted] *Prepared by:* Battelle Memorial Institute, Columbus, Ohio

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center.

[redacted] This handbook characterizes individual pulse reactors, flash x-ray and LINAC facilities on a technical basis for those persons working in the area of transient radiation effects on electronics (TREE). DNA 2432H is arranged to provide the persons who perform TREE experiments with the information concerning facilities which they would require in order to perform an experiment at one of the facilities.

[redacted] X-RAY CROSS SECTION COMPILATION [redacted]

[redacted] *DNA 2433F-1 and -2 and DNA 2433F Supplement* [redacted]

[redacted] *Prepared by:* Kaman Sciences Corporation, Colorado Springs, Colorado.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center. Requests from other than U.S. government agencies must be made through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] The experimental X-ray attenuation cross sections for 94 elements between 0.1 keV and 1 MeV, which were obtained for the period from 1920 through 1970, together with exact photoelectric absorption values for hydrogen, are presented in this compilation.

[redacted] Scattering cross sections were calculated by relativistic SCF methods. These were subtracted from the total attenuation data, and the resulting photoelectric and measured photoelectric absorption cross sections from 1 keV to 1 MeV were fit by a least squares procedure to obtain best values. Interpolations were made for elements and energy ranges for which there were no experimental data. From 0.1 keV to between 1 keV and 10 keV nonrelativistic, self-consistent, independent electron theory was used to calculate photoelectric absorption cross sections. Scattering values were added to all photoelectric cross sections to obtain a best set of attenuation cross sections.

[redacted] NUCLEAR ENVIRONMENT DESCRIPTIONS [redacted]

[redacted] *DASA 2491* (CONFIDENTIAL).

Prepared by: Boeing Company, Seattle, Washington.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center.

[redacted] The phrase "Nuclear Environment Descriptions" includes: (1) nuclear environment criteria; (2) nuclear effects design specifications; and (3) nuclear effects test specifications. This volume provides an introductory discussion of the three types of nuclear environment descriptions, but it is concerned primarily with the first of these descriptions.

[redacted] The major considerations and procedures required for the development of nuclear environment criteria within a logical system development process are described and illustrated. A standard, comprehensive, understandable format for expressing this description is specified. The material presented is not predicated on the administrative procedures of any one military service and is, therefore, of general applicability.

[redacted]

[redacted] NUCLEAR WEAPON THERMAL RADIATION PHENOMENA [redacted]

[redacted] DNA 2500H [redacted]

[redacted] *Prepared by:* Kaman Sciences Corporation, Colorado Springs, Colorado

[redacted] *Availability:* Volumes 2 and 3 were published in July 1974 and February 1974 respectively. Parts of Volume 1 were completed and published separately in February 1974 as DNA 3220Z, "New Thermal Scaling Laws for Low Altitude Nuclear Bursts (U)," and DNA 3223Z, "Atmospheric Transmission of Nuclear Weapon Thermal Radiation (U)." In November 1977, a draft version of Volume 1 was completed. It is expected to be incorporated into one document and published by mid 1978 under the title *New Thermal Scaling Laws for Bursts Below 30 Kilometers.* All published portions are available for qualified users from the Defense Documentation Center.

[redacted] The DNA Thermal Sourcebook is being prepared as a comprehensive summary of theoretical and experimental information on the prompt thermal radiation environment produced by atmospheric nuclear weapons. This book is designed to provide the latest and most reliable information on thermal environments, including both fireball source characteristics and the transport of the fireball radiation through great distances in the atmosphere. The book does not include the numerous considerations relating to target response, although a short appendix on thermal damage effects will be provided.

[redacted] Volume 1 of this sourcebook will treat the following subjects: nuclear weapon outputs, energy deposition in the atmosphere, the physics of fireballs, radiation-hydrodynamics codes, atmospheric transmission phenomena, weapons test data, comparisons of theory and experiment, and environment prediction methods. Volume 2 provides a complete tabulation of all thermal environment measurements made at all U.S. atmospheric nuclear tests through Operation DOMINIC in 1962. Volume 3 is an extensive bibliography of reports, papers, etc., on the subject of nuclear weapons thermal radiation phenomena.

[redacted] TRAPPED RADIATION HANDBOOK

[redacted] DNA 2524H (Unclassified)

[redacted] *Prepared by:* Lockheed Palo Alto Research Laboratory

[redacted] *Availability:* This document has been approved for public release and sale; its distribution is unlimited.

[redacted] The Trapped Radiation Handbook provides useful information and design data for scientists and engineers engaged in the design of spacecraft systems that must operate in the trapped radiation environment. It contains a compilation of useful charts and graphs and abbreviated derivations of equations and developments of concepts in a wide range of subject matter pertinent to the radiation belts. The handbook is intended to be helpful to scientists who are beginning studies or research in this field as well as to scientists who are actively engaged in magnetospheric research. The following subjects are discussed: the magnetosphere; features and mathematical models of the earth's magnetic field; the motion of charged particles in the field; the properties of the particles in the natural radiation belts; source and loss mechanisms; the artificial radiation belts that have resulted from tests of nuclear devices conducted at high altitudes; the phenomenology of nuclear detonations and beta injection processes; the effects of trapped particles (both natural and fission betas) on materials and devices; the irradiation of circular orbit satellites by trapped particles of the natural environment as well as the environment produced by weapon tests L-values, and an estimated wartime environment; the synchrotron radiation emitted by the trapped electrons; and the vulnerability of oper-

[redacted] ational systems in the environments mentioned previously.

[redacted] This handbook is updated on a periodic basis. As of September 1977, five changes have been issued.

[redacted] STATUS OF NEUTRON AND GAMMA OUTPUT FROM NUCLEAR WEAPONS [redacted]

[redacted] *DASA 2567* [redacted]

[redacted] *Prepared by:* Science Applications Incorporated, La Jolla, California.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center on request through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] This report presents a review and evaluation of existing experiments and calculations of neutron and gamma output spectra and intensities. Comparisons of calculated and measured results for a number of devices are described together with possible explanations for some deviations between the experiment and numerical results. In addition, detailed gamma output calculations were performed for Tambourine, using up-to-date neutron and gamma production cross section data.

[redacted] IMPROVED MODELS FOR PREDICTING NUCLEAR WEAPON INITIAL RADIATION ENVIRONMENTS [redacted]

[redacted] *DASA 2615* [redacted]

[redacted] *Prepared by:* Radiation Research Associates, Inc., Fort Worth, Texas.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center on request through Headquarters, Defense Nuclear Agency, Washington, D.C. 20305.

[redacted] DASA 2615 presents a review and evaluation of current data and techniques for predicting the initial radiation exposure at or near the ground surface resulting from a nuclear explosion. State-of-art models were then developed for neutron dose, secondary gamma exposure from neutron interactions in the air and ground, and fission product gamma ray exposure occurring during the first minute following a detonation. The neutron and secondary gamma model, based on Straker's discrete ordinates calculations of neutron transport in an air-over-ground geometry and French's first-last collision method for source height effects, yield results for slant ranges up to 4,800 meters from each of 8 different types of weapons. The results may be adjusted for the desired burst height and air density. The fission-product gamma ray model is based on Monte Carlo air transport calculations by Marshall and Wells. It incorporates source spectra, source decay rates, cloud rise approximations, and hydrodynamic enhancement treatments based on the work of a number of previous investigators. The model provides for a wide variety of burst heights and air densities and provides for slant ranges up to 4,800 meters. The models and the incorporated data were validated through extensive comparison with weapon test results and with other calculated and semi-empirical data.

[redacted] THE MODELING OF NUCLEAR CLOUDS [redacted]

[redacted] DASA 2626 [redacted]

[redacted] *Prepared by:* General Research Corporation, Arlington, VA

[redacted] *Availability:* This document is available to qualified users from the Defense Documentation Center.

[redacted] This modeling was performed in response to the need for a systems program to describe the dust particle environment in a nuclear cloud from a detonation on or near the surface. The flowfield during cloud rise was parameterized using a spherical vortex model empirically

[redacted]

[redacted] fit to data from nuclear tests. This work is supplemental to DASA-2304T [redacted] Volume I, "Nuclear Surface Burst Debris [redacted]" as is also the determination of the lofted mass. The cloud dust loading depends on the height-of-burst in a nonlinear manner which is analyzed and modeled empirically. The particle size distribution of the dust in the cloud is that of the crater ejecta and sweep-up modified by the drag forces exerted by the buoyant and convective air flow. Both during rise and after stabilization, the cloud and dust are translated with the ambient wind. The speed and directional shears cause a time dependent cloud shape, which is important to the systems analyst, for whom the model was developed.

[redacted] The spherical model was completed and reported in DNA 2940T [redacted] "Vortex Dust Model for Rising Nuclear Cloud." Some modifications of the post stabilization model was reported in DNA 2745T [redacted], "New Measurements of Visible Cloud Diameter," and DNA 3158F-1 [redacted] "Post-Stabilization Nuclear Dust Cloud," and have been incorporated in the programming of the vortex model.

[redacted] HANDBOOK OF NUCLEAR WEAPONS AS X-RAY SOURCES [redacted]

DNA 2866H [redacted]

Prepared by: Kaman Sciences Corporation, Colorado Springs, Colorado.

[redacted] *Availability:* Qualified requestors may obtain this document from the Defense Documentation Center.

[redacted] This handbook contains a chronological tabulation of most of the X-ray effects tests that have been conducted by the Department of Defense and the Atomic Energy Commission, as well as a general description of the X-ray spectra and the fluence levels available for experiments on each event. Six illustrative X-ray tests are discussed in some detail. Their X-ray spectra are presented as curves and tabulations and some discussion of their radiation times is given. There is some discussion of the outputs from underground X-ray tests simulating tactical ABM environments.

[redacted] The handbook is not intended to provide all the information required by a person who is not familiar with X-ray effects testing, nor is it for a person whose full time occupation is analysis of X-ray spectra from nuclear weapons. The information is useful to the large majority of the community associated with military effects of X-rays from nuclear weapons. Whether or not this is a "handbook" depends more on the user's definitions than on the author's.

[redacted]

DNA (b)(3)

[redacted] INSTRUMENTS FOR MEASURING NEUTRON AND GAMMA RADIATION FROM NUCLEAR-WEAPON TESTS [redacted]

DNA 2888F [redacted]

[redacted] *Prepared by:* Science Applications Incorporated, La Jolla, California.

[redacted] *Availability:* To be issued during calendar year 1972.

[redacted] DNA 2888 reviews the methods to obtain neutron and gamma ray fluence and spectral data in a nuclear test environment. Approximately forty instruments of those surveyed during this study are described. A complete outline of the experimental techniques employed in these types of measurements is provided, with a description of device input and typical radiation environments encountered during a nuclear test.

[redacted] With few exceptions, only those instruments that have been used in past tests are con-

[redacted]

[redacted]

[redacted] sidered in this report. Instruments to provide neutron and gamma ray dose as a function of time, dose or fluence as a function of energy, and integrated dose were considered. A summary of the relative merits of each instrument is included.

[redacted] THE EFFECTS OF NUCLEAR WEAPONS [redacted]

[redacted] *Prepared and published by:* The U.S. Department of Defense and the U.S. Department of Energy, S. Glasstone and P. J. Dolan, editors.

[redacted] *Availability.* This document may be obtained by contacting the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

[redacted] This book presents as accurately as possible, within the limits of national security, a comprehensive summary of information concerning nuclear weapons effects in an unclassified form. The phenomena of air blast, ground and water shock, thermal radiation, and nuclear radiations associated with nuclear explosions are very complex, and descriptions of these phenomena and their related effects are somewhat technical in nature. However, this handbook has been arranged in such a manner as to serve the widest possible range of readers. Most of the chapters are presented in two parts, the first consisting of a general treatment of a particular topic in a less technical manner and the second discussing some of the more technical aspects. The material is so arranged that the reader will experience no loss of continuity by the omission of any or all of the more highly technical sections, but the technical material is available for the use of those who may have need of such information.

[redacted] The third edition of this book was published in December 1977.

[redacted] VORTEX DUST MODEL FOR RISING NUCLEAR CLOUDS [redacted]

[redacted] DNA 2940T [redacted]

[redacted] *Prepared by:* Science Applications, Incorporated, Arlington, VA

[redacted] *Availability:* Qualified users may obtain this document from the Defense Documentation Center.

[redacted] The transport of soil particles after a nuclear detonation on or near the surface is modeled by the vortex flowfield which has a simple mathematical form. By including appropriate particle drag relations and empirically fitting the vortex parameters to both experimental and hydrocode data, a simpler hydrodynamic model (VORDUM) was obtained to predict the soil particle environment. The boundary condition of zero vertical flow velocity at the surface is obtained by using an image vortex moving downward. The VORDUM results are similar to those obtained using the SHELL hydrocode (developed at AFWL). The model has been applied to yields from less than 1 MT to greater than 10 MT. The pancake geometry of the post stabilization model, reported in DASA 2304T [redacted] Volume I, "Nuclear Surface Burst Debris [redacted] was superseded by this description.

[redacted] The post stabilization cloud geometry was improved by the modeling of the late time cloud reported in DNA 3158 F-1 [redacted] "Post-Stabilization Nuclear Dust Cloud."

[redacted] COMMUNICATION SATELLITE SYSTEMS VULNERABILITY TO NUCLEAR EFFECTS – SELECTED EXAMPLES BY FREQUENCY BAND [redacted]

[redacted] DNA 3185H-1 [redacted]

Prepared by: ESL Incorporated

Availability: Qualified requestors may obtain these documents from the Defense Documentation Center. Each transmittal outside the

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[redacted] agencies of the U.S. Government must have prior approval of the Defense Nuclear Agency.

[redacted] This document describes communication satellite system vulnerability to propagation disturbance induced by nuclear explosions. Examples of the effects of selected nuclear burst on communication satellite system performance are given by frequency band. The satellite systems analyzed are representative of existing, planned, or proposed systems in seven bands extending from 150 MHz to 14 GHz. The examples presented illustrate the approximate duration and extent over which typical systems may experience difficulty. In addition to specific results, the nuclear effects from the selected weapon environments have been parameterized so that these results can be extended to other systems.

[redacted] Among the effects considered are radio wave absorption, thermal noise, signal dispersion, and propagation time delays. The effect of signal dispersion is considered on systems employing frequency division multiplex-frequency modulation (FDM-FM), and digital systems employing phase shift keying (PSK). While not modeled for the selected examples, the potential effects of phase scintillations on systems employing PSK modulation are shown. Potential effects on systems employing Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) using spread spectrum techniques are discussed.

[redacted] ELECTROMAGNETIC BLACKOUT HANDBOOK [redacted]

[redacted] DNA 3380 H-1, 2, 3 (DNA 3380 H-1, [redacted] DNA 3380 H-2, [redacted] DNA 3380 H-[redacted]

[redacted] *Prepared by:* General Electric Company – [redacted]PO.

[redacted] *Availability:* Qualified requestors may obtain these documents from the Defense Documentation Center. Each transmittal outside the agencies of the U.S. Government must have prior approval of the Defense Nuclear Agency.

[redacted] This handbook provides source material on nuclear weapon phenomenology, atmospheric processes, and effects of disturbed atmospheric environments on electromagnetic propagation for use in analysis of radar and communications systems. This edition of the handbook is a revision of DASA 1580 and DASA 1580-1 (same title) and replaces those documents. The handbook is divided into seven chapters plus appendices and is published in three volumes. Chapter 1 provides an introduction to nuclear weapon effects on electromagnetic propagation and a summary of communication and radar system performance in nuclear environments. Chapters 2, 3, and 4 present detailed descriptions of weapon radiations and energy deposition in the atmosphere, the phenomenology of heated regions, and atmospheric processes that affect nuclear weapon-induced atmospheric ionization. Chapters 5, 6, and 7 describe electromagnetic propagation effects and weapon-produced noise sources that can have effect on radar and communication systems. The several appendices include material on the properties of the atmosphere and earth's magnetic field, reference material on electromagnetic propagation and thermal radiation, and parametric scaling for weapon-produced regions and effects.

[redacted] ELECTROMAGNETIC PULSE HANDBOOK FOR ELECTRIC POWER SYSTEMS [redacted] December 1974

[redacted] DNA 3466F [redacted]

[redacted] *Prepared by:* Stanford Research Institute, Menlo Park, California

[redacted] *Availability:* Qualified users may obtain this handbook from the Defense Documentation Center.

[redacted] This handbook has been prepared primarily for the power, communications, and systems engineer who must be concerned with the

[redacted]

[redacted] effects of the nuclear electromagnetic pulse on his system. The power engineer should be aware of the effects of EMP on his transmission and distribution system, and the power users must protect their equipment from the pulse conducted into their facilities on the power lines. The commercial power system can be a major path for coupling the EMP into ground-based systems. The power distribution system forms a very large, completely exposed antenna system that is hard-wired into the customer's facility. Thus, extremely high voltages may be developed on the power conductors, and even if the commercial power is not relied on for system survival, these voltages may be delivered to the system either before commercial power is lost, or by the ground or neutral system after transferring to auxiliary power.

[redacted] Considerable research has been perform[redacted]d on EMP coupling to commercial power systems in an effort to characterize the power distribution lines as EMP collectors, and to determine the effects of major components, such as transformers, lightning arresters, and low-voltage wiring, on the penetration of the received signal into ground-based facilities. This research has entailed development and experimental verification of the theory of coupling to transmission lines. This handbook on the interaction of EMP with commercial power systems has been prepared so that designers and systems engineers can benefit from the results of extensive data already accumulated.

[redacted] A POCKET MANUAL OF THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE EARTH'S ATMOSPHERE [redacted]

[redacted] DNA 3467H [redacted]

Prepared by: General Electric Co., Space Sciences Laboratory, P. O. Box 8555, Philadelphia, Pa. based upon information provided by the Bell Telephone Laboratory, the Lockheed Palo Alto Research Laboratory, and the Santa Barbara Research Center. Information was also obtained from "Aid for the Study of Electromagnetic Blackout," DASA 2499 (1970), the DNA "Reaction Rate Handbook, Second Edition," DNA 1948H (1972), and "The Trapped Radiation Handbook" (1971), DNA 2542H.

[redacted] *Availability:* Qualified requestors may o[redacted]n the handbook from the Defense Documentation Center or from the National Technical Information Service (NTIS).

[redacted] This pocket manual provides a pocket size compendium of current available knowledge concerning the physical and chemical properties of the earth's ionosphere. It is based principally upon data contained in greater detail in DNA Reaction Rate Handbook, Second Edition (1972), DNA 1948H, as well as the other sources mentioned above. A circular slide rule is normally inserted in the flap of the front cover for convenient calculational use.

[redacted] It is anticipated that as important c[redacted]ges occur in relevant information they will be issued to recipients for inclusion in this pocket manual.

[redacted] AID FOR THE STUDY OF ELECTROMAGNETIC BLACKOUT

[redacted] DNA 3499H [redacted]

Prepared by: General Electric Company – TEMPO

[redacted] *Availability:* Qualified requestors may ob[redacted]n this document from the Defense Documentation Center.

[redacted] This report is a revision of DASA 2499 (same title) and replaces that document. The report is a compendium of selected graphs, charts, equations, and relations useful in the analysis of electromagnetic blackout caused by nuclear explosions. Information is provided concerning weapon outputs, ionization source functions, deionization, absorption, phase effects, and noise. The report also contains sections listing atmospheric properties, physical constants, definition of symbols, and a glossary of frequently used terms.

[redacted]

APPENDIX E

GLOSSARY [redacted]

Absorption – The irreversible conversion of the energy of an electromagnetic wave into another form of energy as a result of its interaction with matter.

Absorption coefficient – A number characterizing a given material with respect to its ability to absorb radiation. The linear absorption coefficient refers to the ability of a given material to absorb radiation per unit thickness; it is expressed in reciprocal units of thickness. The mass absorption coefficient refers to the ability of a given material to absorb radiation per unit mass; it is expressed in units of area per unit mass, and it is equal to the linear absorption coefficient divided by the density of the absorbing material.

Acceleration – Time rate of change of velocity. The acceleration due to gravity (g) is 32.2 ft/sec^2.

Activity – The rate of decay of radioactive material expressed as the number of nuclear disintegrations per second.

Adiabatic – Occurring without change in heat content, i.e., without gain or loss of heat by the system involved.

Air burst – See *Burst types.*

Albedo – The fraction of the incident radiation reflected by a material in any manner.

Alpha particle – A particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to the helium nucleus, which has an atomic weight of four and an electric charge of plus two atomic mass and charge units, respectively, i.e., two protons and two neutrons.

Amorphous – Lacking in ordered crystalline structure.

Amplitude – The maximum displacement of an oscillating particle or wave from its position of equilibrium.

Angle of incidence – The angle between the perpendicular to a surface and the direction of propagation of a wave.

Annealing – The process of displacement damage reduction with time, temperature, electrical conditions, etc.

Annealing factor – The ratio of the maximum displacement damage to the displacement damage at a certain time after irradiation. It is a function of time.

Apparent crater – The visible crater remaining after a nuclear detonation. See *Crater.*

Atmospheric transmissivity – The fraction of the radiant exposure received at a given distance after passing through the atmosphere relative to that which would have been received at the same distance if no atmosphere were present.

[redacted]

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Atomic cloud – An all-inclusive term, identified as the hot gases, liquid and solid particles, and vapors produced by a nuclear explosion. Clouds resulting from large yield weapons may penetrate the tropopause and deposit debris in the stratosphere. The cloud contains radioactive fission products. See *Fireball*.

Atomic weapon – See *Nuclear weapon*.

Attenuation – Reduction of the intensity of radiation or a blast or shock wave as a result of passing through any medium.

Base surge – A cloud that rolls out from the bottom of the column produced by a subsurface burst of a nuclear weapon. For underwater bursts, the surge is a cloud of liquid droplets, which has the property of flowing almost as if it were a homogeneous fluid. For subsurface land bursts the surge is made up of small solid particles, but it still behaves like a fluid.

Beta aurora – Fluorescence caused by deposition of beta particle energy in the atmosphere. See *Beta particle*.

Beta particle – A small particle ejected spontaneously from a nucleus of either natural or artificially radioactive elements. It carries a negative charge of one electronic unit and has an atomic weight of 1/1840. See *Electron*.

Bipolar transistor – A transistor that utilizes both minority and majority carriers. Presently, the most common type of transistor.

Black body – A perfect radiator (emitter) of electromagnetic energy. The radiating characteristics of a black body are completely specified by its temperature.

Black body radiation – See *Planckian radiation*.

Blast wave – The shock wave transmitted through the air as the result of an explosion is referred to as a blast wave or air blast. See *Shock wave*.

Blowin – The movement of air into the column of an underwater explosion if the column walls rupture when the enclosed explosion bubble contents are below atmospheric pressure. See *Bubble* and *Column*.

Blowoff – Fragments of material separating from the surface of a material.

Blowout – The escape of underwater explosion bubble contents to the atmosphere at high pressure leading to the formation of a cauliflower cloud considerably wider than the column. See *Bubble* and *Cauliflower cloud*.

Breakaway – The onset of a condition in which the shock front moves away from the periphery of the expanding fireball.

Breaking wave – A wave of such steep slope that it is unable to maintain its shape and loses height by tumbling or falling over.

Breakdown voltage – In semiconductor-junction devices, that voltage that causes appreciable conduction in the reverse direction.

Breakover voltage – The voltage in silicon PNPN devices at which the device switches. That is, the device switches from a high voltage-low current state to a low voltage-high current state.

[redacted]

[redacted]

[redacted]

Bubble – The globe of gas, vapor, and explosion products that forms when an explosion occurs under water.

Bulk conductivity – A measure of the ability of a material to conduct electric current.

Burst geometry – The location of a nuclear detonation with respect to the ground surface, water surface, or bottom.

Burst types:

Air burst – The explosion of a nuclear weapon at such a height that the weapon phenomenon of interest is not significantly modified by the earth's surface. For example, these heights are such that for –

Blast – The reflected wave passing through the fireball does not overtake the incident wave above the fireball ($\sim 160\ W^{1/3}$ ±15 percent).

Thermal radiation – The apparent thermal yield viewed from the ground is not affected by heat transfer to the earth's surface nor by distortion of the fireball by the reflected shock wave ($\sim 180\ W^{0.4}$ ±20 percent for 10 to 100 kt and ±30 percent for other yields).

Fallout – Militarily significant local fallout of radioactive material will not occur. This height generally can be taken to be $100\ W^{0.35}$; however a more conservative estimate of $180\ W^{0.4}$ feet may be desirable for use under some circumstances. See paragraph 5-22, Chapter 5.

Surface burst – The explosion of a nuclear (or atomic) weapon at the surface of the land or water or at a height above the surface less than the radius of the fireball at maximum luminosity (in the second thermal pulse). An explosion in which the weapon is detonated actually on the surface (or within $5\ W^{0.3}$ feet, where W is the explosion yield in kilotons, above or below the surface) is called a contact surface burst.

Subsurface burst – The explosion of a nuclear weapon in which the center of the detonation lies at any point beneath the earth's surface (either ground or water surface).

Calorie – The amount of heat required to raise the temperature of 1 gram of water from 15°C to 16°C at 760 mm Hg pressure.

Camouflet – The cavity resulting from an underground explosion when no rupture of the surface of the earth occurs. See also *Crater*, *True Crater*, and *Apparent Crater*.

Cauliflower cloud – The roughly spherical turbulent cloud which is formed above the column on a very shallow nuclear burst.

Cavitation – The separation of the water particles and the forming of cavities, as a result of the inability of water to withstand the tensional wave reflected from the water surface.

Charge carrier – Any particle possessing a net positive or negative electric charge.

Charge transfer – The movement of electric charge from one material to another. Charge transfer often results in undesirable transient currents, electromagnetic fields, and steady-state voltages.

Circuit saturation – That process in which a circuit is locked in a stable state that often remains after the radiation pulse has subsided (not latchup).

Circuit upset – A circuit response which causes some electrical subsystem or system to malfunction temporarily.

[redacted]

[redacted]

[redacted] *Circumvention* – A general term applied to techniques that allow the circuits in a system to be temporarily perturbed by an ionizing-radiation pulse, but that enable the system to recognize the cause of the perturbations and to ignore any spurious signals or misinformation generated by them.

Cloud chamber effect – See *Condensation cloud.*

Collector junction – One of two junctions in a bipolar transistor. Typically the collector junction is the largest junction and generates the most photocurrent.

Collision frequency – The average number of collisions (involving momentum transfer) per second of a particle of a given species with particles of another or the same species.

Column – The visible column of particulate matter, which may extend to the tropopause (the boundary between the troposphere and the stratosphere) subsequent to the explosion of a nuclear weapon. Also, the hollow cylinder of material thrown up from a subsurface nuclear detonation.

Column jets – Plumes that form on an expanding water column.

Combat ineffective – An individual whose injuries are of such nature that he is no longer capable of carrying out his assigned task.

Component part (component) – A device that performs a function and is not manufactured from other devices (e.g., transistor, integrated circuit, capacitor, resistor).

Component damage – Permanent change in the characteristics of a device due to electromagnetic coupling. See *Coupling.*

Compton current – Electron current generated as a result of Compton processes. See *Compton effect.*

Compton effect – Elastic interaction of gamma rays or X-rays with matter, resulting in the emission of secondary electrons that contain part of the energy of the incident radiation. See *Photoelectric effect.*

Compton electrons – Secondary electrons generated by the gamma rays or X-rays from a nuclear burst absorbed through Compton collisions. See *Compton effect.*

Compton scattering – Scattering photons through their interaction by means of the Compton effect. See *Compton effect.*

Condensation cloud – A mist or fog which temporarily surrounds the fireball after a nuclear explosion in a comparatively humid atmosphere. Since it is similar to the cloud observed by physicists in the Wilson cloud chamber, it is also called the "Wilson cloud." Rapid cooling of the previously heated air surrounding the fireball during the negative pressure phase of the shock wave causes the moisture in the air to condense temporarily, forming a cloud. The cloud is dispelled within a second or so upon return of the air pressure to normal.

Conjugate points – Points at the north and south ends of a geomagnetic field line which are either at corresponding altitudes or at corresponding field strength.

Contamination – The deposit of radioactive material on the surfaces of structures, areas, objects, or personnel, following a nuclear explosion. This material generally consists of fallout in which fission products and other weapon debris have become incorporated with particles of dirt, etc. Contamination can also arise from the radioactivity induced in certain substances by the action of neutrons from a nuclear explosion. See *Decontamination, Fallout, Induced radioactivity, Weapon debris.*

[redacted]

[redacted]

Contour method – The representation of the degree of contamination resulting from a nuclear burst by the use of contour lines to connect points of equal radiation dose or dose rate. See *Isodose lines.*

Conventional current flow – Electric current assumed to flow from the most positive point of the circuit to the most negative point in the circuit relative to ground.

Counterpoise – An electrically continuous conductive material usually installed around the perimeter of a building to reduce the apparent ground resistance.

Coupling – Interaction of electromagnetic fields with electrical systems whereby part of the energy of the field is transferred to the system. Also the energy transfer of a shock wave traveling in one medium, which produces a shock wave in a second medium at their common interface. Also the absorption of radiant energy by a material by conversion to internal energy resulting in a shock wave being developed in the material.

Crack – A rapidly expanding white disc on the water surface whose leading edge follows closely behind the intersection of the underwater shock wave with the surface. The whiteness is believed to be the cavitated region caused by the rarefaction wave, which forms and moves downward when the primary shock is reflected from the surface.

Crater – The pit, depression, or cavity formed in the surface of the earth by an explosion. It may range from saucer shaped to conical, depending largely on the depth of burst. See also *True crater, Apparent crater,* and *Camouflet.*

Crater depth – The maximum depth of the crater measured from the deepest point of the pit to the original level.

Crater radius – The average radius of the crater measured at the level corresponding to the original surface of the ground.

Critical radiant exposure – The thermal radiant exposure required for a particular effect on a material. The unit of critical radiant exposure is the cal/cm^2.

Cross section – A measure of the probability that a nuclear reaction will occur. It is the apparent or effective area presented by a target (e.g., atomic nucleus or other particle) to an oncoming particle or radiation (e.g., X-ray or gamma ray).

Crystalline – Refers to a material (e.g., a semiconductor) possessing an ordered lattice structure.

Curie – The quantity of any radioactive nuclide in which the number of disintegrations per second is 3.7×10^{10}.

Dazzle – See *Flashblindness.*

Debris radiation – Radiation emitted after the first few hundred microseconds after the burst. It is primarily gamma ray and beta radiation.

Decontamination – The process of removing contaminating radioactive material from an object, a structure, or an area. See *Contamination.*

Delamination – Separation of bulk material (see Figure 6-5).

Diffraction – The bending of waves around the edges of objects.

[redacted]

Diffraction loading – The forces exerted upon an object or structure by the blast wave overpressures as the shock front strikes and engulfs it.

Diffusion – That process in which particles (e.g., charge carriers) move from a region of high concentration toward a region of lower concentration.

Direct shock wave – A shock wave traveling through the medium in which the explosion occurred, without having encountered an interface, is referred to as the direct shock wave.

Dispersion – Effects on an electromagnetic wave traversing a region in which the propagation characteristics are frequency dependent.

Displacement – A type of transient and permanent damage in crystalline materials in which atoms are moved from their normal lattice positions.

Dose – See *Radiation dose.*

Dose rate – See *Radiation dose rate.*

Dosimeter – An instrument for measuring the amount of radiation received.

Dosimetry – The process of measuring and providing a quantitative description of a radiation environment, preferably in terms relevant to the radiation effect being studied (e.g., neutron fluence, dose etc.).

Drag loading – The forces exerted upon an object or structure by the dynamic pressures from the blast wave of an explosion, influenced by certain characteristics (primarily the shape) of the object or structure.

D-Region – The region of the ionosphere between about 40 and 90 kilometers altitude. See *Ionosphere.*

Drift – That process in which charge carriers move along the line of action of an electric field.

Ductility – The ability of a material or object to undergo large permanent deformations without rupture.

Dynamic pressure (q) – $q = 1/2\ \rho_s u^2$, where ρ_s is the density of the medium behind the shock front, and u is the particle velocity behind the shock front. The drag force on an object is proportional to the dynamic pressure.

Dynamic pressure impulse – See *Impulse.*

Early transient incapacitation – A temporary inability of a person to perform a required task properly. Onset is shortly after exposure to insult or stress. The incapacitation will be followed by partial or complete recovery of performance ability, frequently temporary in nature.

Eddy current – Current created on the building shielding by the impinging magnetic and electric fields.

E field – Electric field associated with an electromagnetic wave or created by a charge distribution.

Ejecta (throw-out) – Original material dissociated and ejected to the area surrounding a crater. The ejecta creates missile hazards.

[redacted]

Electric surge arrestor (ESA) – Hybrid device which provides protection across the frequency spectrum and voltage spectrum.

Electromagnetic pulse (EMP) – The time-varying electromagnetic radiation that results from a nuclear detonation.

Electromagnetic radiation – Radiation made up of oscillating electric and magnetic fields and propagated with the speed of light. It includes gamma radiation, X-rays, ultraviolet, visible and infrared radiation, and radar and radio waves.

Electromagnetic spectrum – The frequencies (or wave lengths) present in a given electromagnetic radiation. A particular spectrum could include a single frequency or a wide range of frequencies.

Electron – Classically, a unit negatively charged particle usually bound to an atom and orbiting about its nucleus.

Electron volt – The amount of kinetic energy gained by an electron when accelerated through a potential of one volt. (1.6×10^{-12} ergs).

Electrostatic coupling – Capacitive coupling between two parallel lines. See *Coupling.*

Emitter junction – One of two junctions in a bipolar transistor. Typically the emitter junction is the smaller junction and many times the photocurrent generated in it is neglected.

EMP – See *Electromagnetic pulse.*

Energy flux density – The energy of any radiation incident upon or flowing through a unit area, perpendicular to a radiation beam, in unit time.

Energy partition – The distribution of the total energy released by a nuclear detonation among the various phenomena, e.g., nuclear radiation, thermal radiation, and blast. The exact distribution is a function of time, weapon yield, and the medium in which the weapon is detonated.

Energy spectrum – A description of the relative magnitudes of various energy components or energy ranges of electromagnetic radiation or particles.

Epitaxial – The formation of single crystalline material upon a single crystalline substrate by chemical reduction from the vapor or liquid phase. The grown material assumes the same crystal orientation as the substrate.

E-Region – The region of the ionosphere between about 90 to 160 kilometers altitude. See *Ionosphere.*

Exposure – A measure of the radiation energy available (the dose in air). Exposure generally is specified in roentgens.

Exposure rate – A measure of the radiation energy available per unit time (the dose rate in air). Exposure rate generally is specified in roentgens per second or roentgens per hour.

Factor – A multiplier, frequently used to indicate range of coverage. For example, "correct within a factor of two" means correct within a possible range of values between twice and one-half the stated value.

Failure threshold – That exposure which changes one or more material (device) properties to such an extent that the material (device) becomes unsuitable for a specified application.

[redacted]

Fallback – Original material dissociated but not completely removed from the true crater. Upon impact, the fallback and ejecta assist in the development of the hazardous base surge dust cloud.

Fallout – The process or phenomenon of the fallback to the surface of the earth of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The early (or local) fallout is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The delayed (or world-wide) fallout consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried to all parts of the earth. The delayed fallout falls to earth, over extended periods of time ranging from months to years.

Fast neutron – Typically, a neutron with energy exceeding 10 keV (this energy threshold has not been standardized). See *Neutrons, fast.*

Film badge – A photographic film packet in the form of a badge, carried by personnel, for obtaining a measure of gamma and also in some cases, beta and neutron dose. See *Dosimeter.*

Fireball – The visible luminous sphere of hot gases formed by a nuclear explosion.

Fission – The splitting of a heavy nucleus into two (or rarely more) nuclei of lighter elements – the fission products. Fission is accompanied by the emission of neutrons and the release of energy. It can be spontaneous or it can be caused by the impact of a neutron, a fast charged particle, or a photon. The most important fissionable materials for weapons are uranium-235 and plutonium-239.

Fission products – A general term for the complex mixture of substances produced as a result of nuclear fission. A distinction should be made between these and the direct fission products or fission fragments that are formed by the actual splitting of the heavy element nuclei. The fission fragments, being radioactive, immediately begin to decay, forming additional (daughter) products, which are included in the complex mixture of isotopes that is observed at some time after the fission event.

Flashblindness (Dazzle) – Temporary impairment of vision resulting from an intense flash of light. See *Retinal burn.*

Fluence – The number of particles or photons or the amount of energy that enters an imaginary sphere of unit cross-sectional area. It is the time-integrated flux.

Fluorescence – The reemission of absorbed energy by molecules and atoms at the same or longer wavelengths than those that were absorbed.

Flux – The flow of photons, particles, or energy per unit time through an imaginary sphere of unit cross-sectional area.

Forward bias – Voltage applied across a PN junction in such a direction as to cause conduction through the junction i.e., the most positive potential is connected to the P side of the junction.

Forward resistance – The value of the ratio of the forward voltage to the current flowing through the PN junction when that same forward voltage is applied to it. The value varies with forward voltage.

Forward voltage – The voltage applied to a PN junction which forward biases the junction.

Fractionation – The phenomenon which results in a fallout sample being nonrepresentative of the total amount of radioactivity produced by a nuclear explosion. For example a bomb may produce x atoms of one fission product and y atoms of another. Any fallout sample (airborne or on the ground) for which the ratio of the number of these two products is different from x/y is said to be fractionated.

Free air – A region of homogeneous air sufficiently remote from reflecting surfaces or other objects that the characteristics of the direct shock are not modified in any way by reflected shocks or other disturbances arising from scattering objects.

Free air overpressure (sometimes called free air pressure) – The unreflected pressure in excess of atmospheric or ambient pressure created in the air by the incident shock of any explosion.

Free charge – The charge carriers that are capable of moving (i.e., those which are not bound to atoms).

F-Region – The region of the ionosphere above about 160 kilometers.

Fusion – The process by which nuclei of light elements, especially the hydrogen isotopes deuterium and tritium, combine to form the nucleus of a heavier element with a substantial exothermic release of energy.

Gain – With reference to an electronic circuit or device, the ratio of output response to input signal. Gain is a measure of amplification.

Gamma rays – Highly penetrating, high-frequency electromagnetic radiation from the nuclei of radioactive substances. They are of the same nature as X-rays, but of nuclear rather than atomic origin, and are emitted with discrete, definite energies.

Ground zero (GZ) – The point on the surface of land or water vertically below or above the center of a burst of a nuclear weapon; also called surface zero.

Hardening -- The process of decreasing vulnerability to a nuclear explosion by design.

Height of burst – The height above the surface of the earth at which a weapon is burst. Altitude, by contrast, is the height above mean sea level.

H field – Magnetic field associated with an electromagnetic wave or created by an electric current.

Hole – With reference to electronic valence structure of a semiconductor that acts as a positive electronic charge with a positive mass.

Hot spots – Regions in a contaminated area in which the level of radioactive contamination is considerably higher than in neighboring regions.

Impedance – The total opposing force to current flow, a factor of energy dissipation.

Impulse – The product of the average force and the time during which it acts at a given point, or the integral of the curve representing variation of force with time, with integration over the time of interest. In considering the effectiveness of a shock wave in producing damage, it is generally more convenient to employ the concepts of overpressure impulse and dynamic pressure impulse. The overpressure impulse of the positive phase of a blast wave is the integral of the curve representing the variation of overpressure with time, the integration being performed from $t = 0$, the time of arrival of the shock front at a given location, to $t = t_p^+$, the *end* of the positive phase. The dynamic pressure impulse is a similar integral of the dynamic pressure-time curve.

[redacted]

[redacted]

Incapacitation – The inability to perform a required task as the result of a physical or mental disability. See also *Permanent Complete Incapacitation* and *Early Transient Incapacitation.*

Induced radioactivity – Radioactivity that results from certain nuclear reactions in which exposure to radiation results in the production of unstable nuclei. Many materials near a nuclear explosion enter into this type of reaction, primarily as a result of neutron interactions.

Induced shock wave – The shock wave that is induced in a medium when a shock wave traveling in another medium crosses the interface between the two media.

Ineffective – See *Combat ineffective.*

Inelastic scattering – Scattering in which the total kinetic energy of a two-particle system is decreased, and one or both of the particles is or are left in an excited state.

Infrared – That portion of the electromagnetic spectrum occurring between the wavelengths 0.7 and 12 microns.

Initial nuclear radiation – Radiation produced by a nuclear explosion within 1 minute following the burst. It includes neutrons and gamma rays given off at the instant of the explosion, gamma rays produced by the interaction of neutrons with weapon components and the surrounding medium, and the alpha, beta, and gamma rays emitted by the fission products and other weapon debris during the first minute following the burst. See *Residual radiation.*

Internal EMP – A term commonly applied to the electric and magnetic fields generated within an enclosure by the interaction of high energy nuclear radiation (gamma rays, X-rays, neutrons) with the walls.

Interstitial – An atom of a crystalline material located at some point other than a normal lattice position. Interstitials are created during the displacement process. See *Displacement.*

Inversion (atmospheric temperature inversion) – A region in the atmosphere in which the temperature rises with increasing altitude instead of dropping, as it does in the more general case.

Ion – An atom with a net electric charge.

Ionization – The separation of a normally electrically neutral atom or molecule into electrically charged components.

Ionizing radiation – Electromagnetic radiation (gamma rays or X-rays) or particle radiation (neutrons, electrons, etc.) capable of producing ions, i.e., electrically charged atoms or molecules, during its passage through matter.

Ionosphere – That part of the atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves.

I_{pp} – Primary photocurrent. See *Primary photocurrent.*

Irradiance – The incident thermal energy per unit time per unit area. The unit of irradiance is the $cal/cm^2/sec$.

Isobaric – Constant pressure condition.

Isodose lines – A term applied to imaginary contours in a radioactive field on which the total accumulated radiation dose is the same.

[redacted]

[redacted]

Jitter effect – Instability of the signal on the radar indicator.

Kelvin scale – The absolute temperature scale for which the zero is -273°C. Conversion from centigrade to Kelvin is made by adding 273 to the centigrade reading.

Kiloton (kt) – The energy release of one thousand tons of TNT, where 1 ton equals 2,000 pounds and where the energy content of TNT is defined as 1,102 calories per gram.

Latchup – Regenerative device action in transistors or circuits in which an undesired stable condition is attained.

Lattice – The pattern defined by an orderly crystalline structure in a material.

Leakage current – An undesirable reverse current across a semiconductor junction.

Lethal gust envelope – The boundary of the area in any given plane within which the gust loading effects from an explosion inflict sufficient structural damage to destroy a given aircraft.

Linear circuit – An electronic circuit in which voltages and currents can be continuously variable.

Lip height – The height above the original surface to which earth is piled around the crater formed by an explosion.

Loading – The forces imposed upon an object.

Loop – A closed path or circuit over which an electric signal can circulate.

Lossy devices – Devices that convert portions of the input energy into heat, which is lost to the surrounding medium.

Lossy field coupling – Coupling of an electromagnetic field into an electrical system so that part of the energy is lost due to radiation. See *Coupling.*

Mach stem – The shock formed by the fusion of the incident and reflected shocks from an explosion. The term usually is used with reference to an air-propagated wave reflected from the surface of the earth, generally nearly vertical to the reflecting surface. See *Shock front.*

Magnetic coupling – Energy departed to (or voltage induced in) a loop of finite area due to a change in flux linkages within the loop.

Magnetic conjugate points – Points at the north and south ends of a geomagnetic field line that are either at corresponding altitudes or at corresponding magnetic field strengths.

Majority carrier – In semiconductors, the type of carrier that constitutes more than half the total number of carriers. The majority carriers are electrons in an N-type semiconductor and holes in a P-type semiconductor.

Mean free path – Average distance traveled by particles before interaction or average distance a single particle travels between interactions.

Median lethal dose – The amount of radiation received over the whole body which would be fatal to about 50 percent of a specified animal. The median lethal dose for humans is not well established, but for the purpose of this manual it is assumed to be 450 rads, if the total dose is delivered within a period of 24 hours or less. Sometimes abbreviated as MLD or LD-50.

Megaton (Mt) – The energy release of a million tons of TNT (10^{15} calories). See *Kiloton.*

[redacted]

Metal-oxide-semiconductor (MOS) transistor – A field-effect transistor consisting of a silicon chip, a silicon oxide, and a metal contact.

Micron (μ) – A unit of length equal to 10^{-6} meters, 10^{-3} meters, 10^{-3} millimeter, or 10^4 Angstrom units.

Millibar – One thousand dynes per square centimeter, a unit of measure of atmospheric pressure.

Minority carrier – The type of carrier that constitutes less than half the total number of carriers in a semiconductor. The minority carriers are holes in an N-type semiconductor and electrons in a P-type semiconductor.

Minority-carrier lifetime – The time period starting with the creation of a minority carrier and ending with its being recombined.

Mobility – The ease with which carriers move through a semiconductor either through random motion or when they are subjected to electric forces.

Monte Carlo method – A method of solution of a group of physical problems by means of a series of statistical experiments which are performed by applying mathematical operations to random numbers.

MOS – Metal-oxide-semiconductor.

Negative phase – That portion of the blast wave in which pressures are below ambient atmospheric pressure.

Neutron – An electrically neutral particle which is one of the fundamental particles making up the nucleus of all atoms except hydrogen. It has nearly the same weight as the hydrogen nucleus (atomic weight 1). The neutron under appropriate conditions is capable of causing fission of U^{235} or Pu^{239} and certain other radionuclides. In the fission process other neutrons are produced, which can cause fission in additional U^{235} or Pu^{239} atoms. This multiplication process, triggered by neutrons, gives rise to the chain reaction which makes nuclear explosions possible.

Neutron capture – A basic interaction of neutrons with matter. Neutron capture can result in the generation of gamma rays and/or charged particles.

Neutron fluence – The number of neutrons entering an imaginary sphere of unit cross-sectional area. It is equal to the time integrated neutron flux. It is generally expressed as n/cm^2. If expressed as Nvt, N is the neutron density (n/cm^3) in the beam v is the average speed (cm/sec), and t is the time duration. The spectrum should be specified with the fluence, e.g., n/cm^2 (fission spectrum).

Neutron flux – The flow of neutrons into an imaginary sphere of unit cross-sectional area. It is generally expressed as $n/cm^2/sec$. If expressed as Nv, N is the neutron density in the beam (n/cm^3), and v is the average speed (cm/sec). The spectrum should be specified with the flux, e.g., $n/cm^2/sec$ (fission spectrum).

Neutrons, fast – Neutrons with energies exceeding 10 keV, although sometimes different energy limits are given. See *Fast neutrons.*

Neutrons, thermal – Neutrons in thermal equilibrium with their surroundings. At room temperature their mean energy is about 0.025 electron volts (eV).

Nonlinear zone – A wedge-shaped zone in water, which increases in depth as the range from the burst point increases, and within which anomalous reflections affect the underwater pressure history.

[redacted]

N type – This term refers to semiconductor material which has had certain impurities added so that there are excess electrons available for conduction.

Nuclear radiation – Any or all of the radiations emitted as a result of the radioactive decay of a nucleus. The radiations include gamma radiation (of electromagnetic character) and particle radiation (alpha particles, positive and negative beta particles, and neutrons).

Nuclear Weapon – Means the same as "Atomic Weapon" as that term is defined in Section 11d, Public Law 703, 83rd Congress, viz: any device utilizing atomic energy, exclusive of the means for transporting or propelling the device (where such means is a separable and divisible part of the device), the principal purpose of which is for use as, or for development of, a weapon, weapon prototype, or a weapon test device.

Nuclide – A general term referring to all nuclear species, both stable and unstable, of the chemical elements as distinguished from the two or more nuclear species of a single chemical element, which are called isotopes.

Overpressure – The transient pressure, usually expressed in pounds per square inch, exceeding existing atmospheric pressure manifested in the blast wave from the explosion. During some period of the passage of the wave past a point, the overpressure is negative.

Overpressure impulse – See *Impulse.*

Pair production – A basic interaction of photons with matter (see Figure 6-1c).

Passive elements – Mainly filter devices and circuits which remove portions of the energy spectrum not needed by system operation.

Performance decrement (personnel) – Reduction of efficiency in performance of a required task, such as increased reaction time, increased performance time, and/or increased error rate.

Period of vibration (period) – The time for one complete cycle of oscillation or vibration.

Permanent complete incapacitation (personnel) – The inability to perform any task as the result of a physical or mental disability that will not improve subsequently.

Permanent effects – Changes in material properties that persist for a time long compared with the normal response time of the system of which the material is a part.

Photocurrent – A flow of excess charge carriers generated in a material or device by ionizing radiation.

Photoelectric effect – The process whereby a gamma ray or X-ray photo, with energy somewhat greater than that of the binding energy of an electron in an atom, transfers all of its energy to the electron, which is removed from the atom.

PIN junction – This type of diode has intrinsic (undoped) semiconductor material between the P and N-doped materials. See *N type* and *P type.*

Planar diffused – A technique for manufacturing semiconductor devices by introducing dopant elements into the semiconductor wafers by selective diffusion from the surface. All junction-surface intersections are protected from the ambient atmosphere by a passivation layer, typically silicon oxide, grown on the device structure.

[redacted]

[redacted]

Planckian radiation – The energy distribution of the radiation emitted by a black body radiator. The spectrum is determined by the temperature and is given by Planck's radiation law (see paragraph 4-2, Chapter 4). See *Black body.*

Plastic deformation – That deformation from which a deformed object does not recover upon removal of the deforming forces.

PNP – A three-layer semiconductor structure that constitutes a bipolar transistor. See *N type* and *P type.*

Popcorning – The ejection of dust particles from certain types of surface upon absorption of the thermal radiation emitted by a nuclear detonation.

Potting – The complete immersion of encapsulation of devices or circuitry in an insulating compound. Potting typically is used in TREE work to reduce the effects of leakage currents caused by radiation induced air ionization.

Positive phase – That portion of the blast wave in which pressures are above ambient atmospheric pressure.

Precursor -- A pressure wave which precedes the main blast wave of a nuclear explosion.

Primary photocurrent (I_{pp}) – Current which flows across a semiconductor junction as a result of ionization.

Prompt conductivity – Conductivity resulting from exposure to prompt gamma radiation.

Prompt gamma rays – Gamma rays produced in fission and fusion reactions and as a result of nuclear excitation of the weapon materials.

Prompt neutrons – Neutrons generated by the fission and fusion reactions of a nuclear weapon burst.

Proton – A positively charged particle with a mass approximately the same as that of a neutron. In nature, protons are bound in the nuclei of atoms.

P type – Semiconductor material which has had certain impurities added so that there is an excess of holes available for conduction.

Punch through – Breakdown mechanism in transistors caused by an arc discharge at the junction.

Rad – A unit of absorbed dose of radiation; it represents the absorption of 100 ergs of nuclear (or ionizing) radiation per gram of the absorbing material or tissue. When specifying dose, the absorbing material must be indicated, e.g., C, Si, tissue.

Radiant energy – See *Thermal radiation.*

Radiant exposure – The incident radiant energy per unit area, generally expressed in cal/cm^2.

Radiant power – Time rate of radiant energy emission. The useful units of radiant power are kt/sec or cal/sec.

Radiation dose – The total amount of radiation absorbed by material or tissue, commonly expressed in rads. In the case of materials, the radiation dose may be expressed in cal/gm (material) or ergs/gm (material).

[redacted]

[redacted]

[redacted] *Radiation dose rate* – The time rate of absorbing radiation, commonly expressed in rads/sec or rads/hr. In the case of materials the radiation dose rate may be expressed in cal/gm/sec (material) or ergs/gm/sec (material).

Radioactivity – The property of certain nuclides of undergoing a spontaneous nuclear transformation in which the nucleus emits particles and/or gamma rays, or undergoes spontaneous fission, or in which the atom emits X-rays or Auger electrons following orbital electron capture or internal conversion. As a result of the emission of particles, the radioactive isotope is converted (or decays) into the isotope of a different (daughter) element which may or may not also be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (non-radioactive) end product is formed.

Rarefaction wave – When a shock wave in a medium strikes the interface between this medium and a less dense medium, part of the energy of the shock wave induces a shock wave in the less dense medium. The remainder of the energy forms a rarefaction or tensile wave which travels back through the denser medium.

Reaction rate – In chemical kinetics, the time derivative of the concentration of a given species is called the reaction rate of that species; it is also called the velocity or speed of the reaction.

Recombination – A process by which a hole-electron pair is annihilated, usually by direct combination of a free electron with a free hole, by capture of a free electron by an excited center containing a hole, or by capture of a free hole by an excited center containing an electron. Recombination transistions of these types may be radiative.

Recombination center – In some electron-hole recombinations the electron (hole) in the conduction band does not make a direct transition to the valence band but first occupies an intermediate state in the forbidden gap called a recombination center, which is associated with lattice imperfections or chemical impurities.

Reflected pressure – The pressure along a surface at the instant a blast wave strikes the surface.

Reflected shock wave – When a shock wave traveling in a medium strikes the interface between this medium and a denser medium, part of the energy of the shock wave induces a shock wave in the denser medium and the remainder of the energy results in the formation of a reflected shock wave which travels back through the less dense medium.

Refraction – Bending of an electromagnetic wave path when it traverses a region whose propagation characteristics are a function of position.

Relative air density – The ratio of air density under a specified condition to the air density of the standard atmosphere at sea level (see Tables 2-1 and 2-2, Chapter 2).

Residual nuclear radiation – Nuclear radiation, chiefly beta particles and gamma rays, which persists for some time following a nuclear explosion. The radiation is emitted mainly by the fission products and other bomb residues in the fallout, and to some extent by earth and water constituents, and other materials, in which radioactivity has been induced by the capture of neutrons.

Response – The action of an object under the applied loading.

Retinal burn – A permanent eye injury caused when the retinal tissue of the eye is excessively heated by the focused image of the fireball.

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Rise time – The time interval from blast wave arrival to the time of peak overpressure in the blast wave.

Roentgen – A unit of exposure to gamma rays or X-rays. It is defined precisely as the quantity of gamma ray or X-ray radiations such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit quantity of electricity of either sign. It is approximately equivalent to a dose of 87.7 ergs/gm in air [0.877 rads (air)] and 97 ergs/gm in tissue [0.97 rads (tissue)]. For the purposes of this manual, an exposure of 1 roentgen is equivalent to a radiation dose of 1 rad (tissue).

Rupture zone – Zone extending from the earth media-rubble interface in which stresses created by the detonation cause fracture and crushing of the material. The rupture zone enhances the use of cratering for the demolition of certain hard targets and for quarrying operations.

Scattering – Change in direction of propagation of radiation caused by collision with particles.

Scavenging – That process by which fission products are removed from the radioactive cloud by becoming attached to earth, rain, or other particles.

Scintillation – Random fluctuations in the magnitude and direction of an electromagnetic wave as it traverses an inhomogeneous medium.

Secondary electron – An electron that is emitted as a result of bombardment of a material by high energy radiation.

Secondary EMP – Same as internal EMP.

Secondary photocurrent – The primary photocurrent in a transistor can be of sufficient magnitude to forward bias the base-emitter junction and hence cause "normal" current to flow. The collector current thus produced is called the secondary photocurrent.

Semiconductor devices – Devices that use material that has a conductivity between that of a good conductor and a good insulator. Transistors, diodes, and integrated circuits belong to this class of devices.

Semiconductor junction – Two adjacent semiconductor materials that differ in the polarities of their majority carriers.

Shake – A nonstandard unit of time used in nuclear physics, equal to 10^{-8} second.

Shielding – 1. Material of suitable thickness and physical characteristics used to protect personnel from radiation during the manufacture, handling and transportation of fissionable and radioactive materials.

2. Obstructions that protect personnel or materials from the effects of a nuclear explosion.

3. Electrically continuous housing for a facility, area, or component, used to attenuate impinging electric and magnetic fields both by absorption and reflection.

Shock front – The boundary at which the medium being traversed by a shock or blast wave undergoes abrupt changes in velocity, pressure, and temperature.

Shock strength – The ratio of the peak blast wave overpressure plus the ambient pressure to the ambient pressure.

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Shock wave – The steep frontal compression or pressure discontinuity that advances through a medium rapidly as the consequence of a sudden application of pressure to the medium. Its form depends on the magnitude of the pressure and the displacement of the medium as the wave progresses. In soil the shock wave is commonly referred to as the ground shock; in water, the water shock; and in air, the air blast.

Slant range – The direct distance between an explosion and a point.

Simulation – To produce the effect of a nuclear burst on a particular material or device by means other than a full scale explosion.

Space charge – The electric charge carried by a cloud or stream of electrons or ions in a vacuum or a region of low gas pressure, when the charge is sufficient to produce local change in the potential distribution.

Spallation – The removal of fragments from the back surface of a material (see Figures 6-5 and 9-43, Chapters 6 and 9, respectively).

Spectral distribution – The distribution of energy by wave length over the electromagnetic spectrum.

Steady state – Constant with time.

Steady state primary photocurrent – The constant primary photocurrent that would be observed to flow across a semiconductor junction under continuous irradiation.

Subsurface burst – See *Burst types*.

Sure-kill level – A set of environmental conditions under which it is 100 percent certain that the system mission cannot be executed.

Sure-safe level – A set of environmental conditions under which it is 100 percent certain that the system mission can be completed.

Surface burst – See *Burst types*.

Synchrontron radiation – Electromagnetic radiation emitted by a high-energy electron moving in a magnetic field.

Tensile wave – See *Rarefaction wave*.

Thermal energy – See *Thermal radiation*.

Thermal pulse – The radiant power vs time pulse from a nuclear weapon. See *Radiant power*.

Thermal radiation – Electromagnetic radiation from a nuclear weapon, which is emitted in the wavelength range from 0.2 micron in the ultraviolet, through the visible, to 12 microns in the infrared. Also called *Thermal energy* and *Radiant energy*.

Thermonuclear – An adjective referring to the process involving the fusion of light nuclei such as those of deuterium and tritium.

TNT effects equivalence – The expressing of the effect of a particular phenomenon of a nuclear detonation in terms of the amount of TNT that would produce the same effect.

TNT energy equivalent – Total energy of a nuclear detonation expressed in terms of the amount of TNT required to produce an equivalent energy.

[redacted]

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[redacted]

Transient effects – Changes in material properties that persist for a time shorter than, or comparable to, the normal response time of the system of which the material is a part.

Transient radiation – A pulse or burst of radiation whose pulse width at half-maximum intensity generally ranges from nanoseconds to a few milliseconds.

Transistor – A semiconductor device that uses a small current to control a much larger current.

Transition zone (region) – A zone extending above the earth's surface in which the weapon phenomenon of interest from a burst in the zone will be modified by the presence of the earth's surface. See *Burst types: Air burst.*

Transmissivity - See *Atmospheric transmissivity.*

Trapping – That process in which a free charge carrier is captured, and once captured, has a greater probability of being reexcited to a free state than of recombining with a carrier of the opposite polarity.

Trapping center – A site in a solid at which a free electron or hole may be captured, and in which the charge carrier, once captured, has a greater probability of being thermally reexcited to a free state than of recombining with a carrier of the opposite sign. See *Trapping.*

TREE – Transient-radiation effects on electronics.

TREES – Transient-radiation effects on electronic systems.

Triple point – The intersection of the incident, reflected and fused shock fronts produced by an explosion in the air. Because of the variation of the angle of incidence as the blast wave expands, and because the reflected wave, in a heated, denser medium, travels faster than the incident wave, the height of the triple point increases with the distance from the explosion. See *Mach stem.*

True crater – The crater excluding fallback material. See *Crater.*

Ultraviolet – That portion of the electromagnetic spectrum occurring between the wavelengths 0.2 and 0.4 micron.

Underground burst – See *Burst types.*

Underwater burst – See *Burst types.*

Upthrust – Deformation material pushed up around a crater, but not dissociated from the earth media by a nuclear blast.

Vacancy – An empty lattice site in a crystalline material.

Visible – That portion of the electromagnetic spectrum occurring between 0.4 and 0.7 micron. The term luminous also is applied to radiation in this region.

Visibility – The horizontal distance at which a large, dark object can just be seen in daylight near the horizon.

Wave length – The distance between two similar and successive points on an alternating wave, as between maxima.

Wave train – A series of alternating crests and troughs of a wave system resulting from a surface disturbance.

[redacted]

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[redacted]

Weapon debris – The residue of a nuclear weapon after it has exploded; that is, the materials used for the casing and other components of the weapon, plus unexpended plutonium or uranium, together with fission products.

Wilson cloud – See *Condensation cloud.*

Wind shear – A relatively abrupt change with altitude of wind direction or magnitude.

X-rays – High frequency electromagnetic radiation produced by any of three processes: radiation from a heated mass (e.g., a black body); deceleration of a charged particle; electron transitions between atomic energy levels, usually excited by incident beams of high-energy particles, resulting in characteristic, discrete energy levels.

Yield – The energy released in a nuclear explosion, usually measured by the estimated equivalent amount of TNT required to produce the same energy release. See *TNT energy equivalence.*

[redacted]

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APPENDIX F

LIST OF SYMBOLS [redacted]

[redacted] This manual covers a wide variety of subject matter. Consequently, it has been necessary to use a large number of symbols to represent quantities of interest. In many-cases, one symbol has different meanings in different parts of the manual. This was done for two reasons:

- the large quantity of symbols;
- the desire to use accepted symbols for specific quantities; e.g., the symbol σ is used for the Stefan-Boltzmann constant, conductivity, stress, radiation interaction cross section, and for the standard deviation in probability equations, for each of which σ is the usual symbol.

If a symbol has one meaning throughout the manual, that meaning is shown without indication of location. If a symbol has one meaning in several chapters and other meanings in isolated cases, the most frequent meaning is listed without indication of location, and other meanings are listed as exceptions, with the location of the exceptions being indicated by chapter and, in some cases by section of a chapter. When a symbol has different meanings in several isolated locations, each location is indicated by chapter.

[redacted] Except where specifically indicated in the text, the subscript 1 is reserved for burst parameters (overpressure, height of burst, distance, etc.) for a 1 kiloton explosion, and the subscript 0 is reserved for standard sea level atmospheric properties (pressure, temperature, density, etc.). Symbols with these subscripts having these meanings are not listed separately below. Exceptions are listed.

[redacted] One further convention should be noted. Many logarithmic and semi-logarithmic graphs are used in the manual. In most cases, either a full logarithmic grid is shown or tick marks are provided for each digit within a decade. In a few cases, unmarked tick marks are not shown for all digits (e.g., Figure 8-7). In all such cases, the tick marks are shown for the digits 2, 4, 6, and 8 (times the indicated power of ten for that decade).

Symbol	*Designation*
A	Area of fission debris from a high altitude explosion (Chapter 8; Chapter 17).
A	Area of an object exposed to the air blast wave of a nuclear explosion (Section II, Chapter 9; Chapter 14; Appendix A).
A	Thermal absorption coefficient (Section III, Chapter 9).
A	Area of transistor PN junction (Section VII, Chapter 9).
A	Cross-sectional steel area per inch of width of a deeply buried horizontal steel arch (Chapter 11).

[redacted]

Symbol	*Designation*
A	Reference area for determination of a missile ballistic coefficient (Chapter 16).
A_e	Effective thermal absorption coefficient (Section IV, Chapter 9).
A_{dir}	Energy absorbed in a material as the result of X-ray interactions (Section V, Chapter 9).
A_{fb}	Absorption of electromagnetic signals propagating through a fireball (Chapter 8).
A'_{fb}	Absorption of a 1,000 MHz signal propagating through a fireball (Chapter 8).
A_{max}	Maximum radius of the bubble created by an underwater explosion (See A_n, A_1, A_2, A_3) (Chapter 2).
A_n	Maximum radius of a migrating and pulsating underwater bubble during its n^{th} period.
A_p	One-way absorption due to ionization from prompt nuclear radiation of an electromagnetic signal propagating on an oblique path outside of the fireball (Chapter 8).
A'_p	One-way absorption due to ionization from prompt nuclear radiation of an electromagnetic signal propagating on a vertical path outside of the fireball (Chapter 8).
A_1	Radius of the bubble from an underwater nuclear explosion at the first maximum expansion (equal to A_{max}).
A_2	Radius of the bubble from an underwater nuclear explosion at the second maximum expansion.
A_3	Radius of the bubble from an underwater nuclear explosion at the third maximum expansion.
A_β	One-way absorption of an electromagnetic signal propagating on an oblique path outside of the fireball caused by beta particles and their ionization.
A'_β	One-way absorption of an electromagnetic signal propagating on a vertical path outside of the fireball caused by beta particles and their ionization.
A_γ	One-way absorption of an electromagnetic signal propagating on an oblique path outside of the fireball caused by ionization from delayed gamma rays.
A'_γ	One-way absorption of an electromagnetic signal propagating on a vertical path outside of the fireball caused by ionization from delayed gamma rays.
Ag	Maximum acceleration of ground particles from a near surface (air) burst, surface burst, or subsurface burst.

Symbol	*Designation*
AR	Aspect ratio* of aircraft wing or horizontal tail or of an isolated vertical tail.
AR_B	Aspect ratio of the vertical tail of an aircraft in the presence of the fuselage.
AR_{eff}	Effective aspects ratio of the vertical tail of an aircraft.
AR_{HB}	Aspect ratio of the vertical tail of an aircraft in the presence of both the horizontal tail and the fuselage.
B	Brightness of an object relative to its background. May be positive if the object is lighter than the background, or negative if the object is darker than the background (Chapter 3).
B	Buildup factor. The increase in flux (or fluence) at a point relative to that that would be present without scattered photons or particles (Chapter 4).
B	Parameter that describes the overpressure contribution to the total impluse delivered by the air blast wave to an object (Chapter 14).
B'	Brightness of the background surrounding an object (Chapter 3). (See paragraph 3-7 for the relationship between B and B' as used in Chapter 3 to define "contrast.")
B_φ	Azimuthal magnetic field of the electromagnetic pulse (EMP).
BH_i	Burst height parameters for the calculation of overpressure effects on aircraft in-flight or parked (Chapter 13).
C	Contrast between brightness of an object and its background (Chapter 3).
C	Parameter that describes the dynamic pressure contribution to total impulse (Chapter 14).
C	Point of intersection of a missile with the shock front (Chapter 16).
C_d	Drag coefficient, which relates the force on an object to the incident dynamic pressure or atmospheric pressure in the case of a missile.
C_{db}	Drag coefficient for the back side of an object, i.e., the side away from the explosion.
C_{df}	Drag coefficient for the front side of an object, i.e., the side facing the explosion.
$C_{L\alpha}$	Aerodynamic coefficient for aircraft wings and/or horizontal tails.

[redacted]spect ratio of an isolated aircraft component (wing, horizontal tail, or vertical tail) is the ratio of the square of the span (tip to center of fuselage) of the component to the area of the component.

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Symbol	*Designation*
$\overline{C}_{L\alpha}$	Lift coefficient for a vertical tail on an aircraft.
$C_{L\alpha}^{MR}$	Lift curve slope for the main rotor of a helicopter.
$C_{L\alpha}^{W}$	Lift coefficient for a helicopter wing.
C_M	Correction factor for material properties of deeply buried horizontal reinforced concrete arches (Chapter 11).
$C_{N\alpha}$	Normal force coefficient (missiles or aircraft).
C_p	Specific heat at constant pressure.
C_{tp}	Correction factor to obtain an equivalent triangular waveform for overpressure (Chapter 2).
C_{tq}	Correction factor to obtain an equivalent triangular waveform for dynamic pressure (Chapter 2).
C_V	Specific heat at constant volume.
C_{α}^{p}	Aspect ratio correction factor for the strength of two-way slabs (Chapter 11).
C_{γ}	Correction factor to obtain the gamma ray intensity parameter for high altitude weapon debris (Chapter 8).
C.G.	Center of gravity.
CI	Combat ineffectiveness.
D	Maximum displacement of a buried structure or piece of equipment that results from ground shock (Chapter 2).
D	Distance from an explosion or from high altitude debris to the point of interest along a path parallel to the surface of the earth (Chapter 8).
D_a	Depth of the apparent crater, which is the distance from the bottom of the visible portion of the crater to the original ground surface (see Figure 2-70).
$D_{a\ell}$	Height of the crest of a crater lip measured from the bottom of the visible portion of the crater (see Figure 2-70).
D_c	Thickness of roof or wall of a buried structure (Chapter 11).
D_d	Maximum offset of the debris from an explosion above 200 kilometers altitude, which is the distance between lines through the center of the burst and the center of the debris after it travels down the magnetic field lines and stabilizes each line being perpendicular to the surface of the earth (see Figure 8-18).

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Symbol	*Designation*
D_{max}	Maximum radius of the water column formed by an underwater explosion.
D_N	The neutron dose from a nuclear explosion at some specified location on or near the surface of the earth.
D_s	Depth of the section of a structural member (see Figure 11-33).
$D_{\gamma f}$	That portion of the initial nuclear radiation dose received at a specified location on or near the surface of the earth that results from gamma rays that are produced by fission product decay.
$D_{\gamma s}$	That portion of the initial nuclear radiation dose received at a specified location on or near the surface of the earth that results from gamma rays that are produced by neutron interactions.
DF	Dynamic factor – a parameter used in the determination of incremental lift of aircraft by the air blast wave.
DOB	Depth of burst.
D-Region	See Glossary.
$\dot{D}$	Gamma radiation exposure rate (Section VI, Chapter 9).
$\dot{D}_t$	Residual gamma radiation dose rate at time *t* after the explosion (Chapter 5).
$\dot{D}_1$	Residual radiation dose rate one hour after an explosion.
$\dot{D}_{\gamma p}$	Peak gamma ray dose rate.
E	Young's modulus of elasticity (Chapter 2 and Chapter 11).
E	Water shock energy flux from an underwater explosion (Chapter 2).
E	Energy of a photon (Chapter 4).
E	Hydrodynamic enhancement factor, which is the factor by which the initial gamma dose is increased as a result of the reduced air density behind the shock front (Chapter 5).
E	Peak value of the electric field of the radiated electromagnetic pulse (EMP) (Chapter 7).
E	Internal energy per unit mass of material (Section V, Chapter 9; Appendix A).
E_c	Potential energy of a cavity created by an underwater explosion.
E_{itan}	Tangential component of an incident electromagnetic field.

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Symbol	*Designation*
E_o	Explosive yield of an underwater charge (Section IV, Chapter 2).
E_o	X-ray yield of a weapon (Chapter 4).
E_r	Peak radial electric field of the electromagnetic pulse (EMP).
E_s	Heat of sublimation of a material (Section V, Chapter 9).
E_s	Energy density of air behind a shock front (Appendix A).
E_{so}	Heat of sublimation at absolute zero, i.e., the energy required to form the saturated vapor from the solid at a temperature of absolute zero.
E_θ	Peak transverse electric field of the electromagnetic pulse (EMP).
EMP	Electromagnetic Pulse. The time varying electromagnetic radiation resulting from a nuclear explosion.
$E(m)$	The specific energy deposited by X-rays corresponding to a depth for which the integrated mass is m.
E-Region	See Glossary.
$\bar{E}$	Restrained modulus of a medium transmitting a shock wave.
$\bar{E}_g$	Electric field of an electromagnetic pulse that is refracted into the ground.
$\bar{E}_i$	Incident electric field of the electromagnetic pulse (EMP).
F	Force (Appendix A).
F_N	Neutron dose function (yards^2 rads/kt) (Section I, Chapter 5).
F[illegible]	Force exerted on an object by the winds accompanying a blast wave (Appendix A).
$F_{\gamma f}$	Fission product gamma ray dose function (rads/kt) (Section I, Chapter 5).
$F_{\gamma s}$	Secondary gamma ray dose function (yards^2 rads/kt) (Section I, Chapter 5).
FF	Fraction of total weapon debris that is deposited in one of three regions subsequent to a high altitude nuclear explosion (*FF*1, *FF*2, and *FF*3 are deposited in regions 1, 2, and 3 respectively, as defined in Chapter 8).
F-Region	See Glossary.
$F(t)$	Time dependent gain degradation of a transistor that is exposed to radiation (Section VII, Chapter 9).
$F(u)$	Density function of the normalized Planck distribution (Chapter IV).

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Symbol	Designation
G	Grüneisen ratio of a material (Section V, Chapter 9).
G_A	One value on the intercept/load matrix of axial rigid body loads on missiles (Chapter 16).
G_I	Maximum load on a missile at blast wave intercept (Chapter 16).
G_N	One value on the intercept/load matrix of normal rigid body loads on missiles (Chapter 16).
G_T	One value on the intercept/load matrix of total rigid body loads on missiles (Chapter 16).
$G(u)$	Cumulative distribution function of the normalized Planck distribution (Chapter 4).
GW	Gross weight of an aircraft (Chapter 13).
GZ	Ground zero. That point on the surface of the earth that is directly below, directly above, or at the point of an explosion (**see** SGZ, SZ).
H	Height of the Mach stem (Section I, Chapter 2).
H	Depth to which the air-induced shock wave extends into the earth during the effective duration of the shock (Section III, Chapter 2).
H	Amplitude of the maximum of the first envelope, trough to crest, of a water wave generated by underwater explosions (Section IV, Chapter 2).
H	Time of an explosion, i.e., H + 1 hour indicates a time of one hour after an explosion (Chapter 5 and Chapter 14).
H	Heat of fusion (Chapter 13).
$H_{a\ell}$	Apparent height of a crater lip.
H_{av}	Average cover over a structure that is buried in soil (Chapter 11).
H_c	Depth of cover over the crown of a structure that is buried in soil (Chapter 11).
H_{max}	Limiting height of a water wave that can propagate over deep water in a stable manner (Michell limit).
H_R	Range dependent burst height adjustment factor for the fission product gamma ray component of the initial nuclear radiation dose.
H_W	Yield dependent burst height adjustment factor for the fission product gamma ray component of the initial nuclear radiation dose.

Symbol	*Designation*
H_1	Detonation height correction factor for the neutron and secondary gamma ray components of the initial nuclear radiation dose (Chapter 5).
H.E.	High explosive.
HOB	Height of burst.
$\overline{H}$	Magnetic field of the electromagnetic pulse (EMP).
$\overline{H}_i$	Incident magnetic field of the electromagnetic pulse (EMP).
$\overline{H}_r$	Reflected magnetic field of the electromagnetic pulse (EMP).
$\overline{HR}_i$	Horizontal range parameters for the determination of the vulnerability of aircraft to overpressure (i = 1, 2, 3).
I	Either overpressure or dynamic pressure impulse.
I	Current produced in a conductor as a result of coupling of energy from the electromagnetic pulse (EMP) (Section VIII, Chapter 9).
I_B	Air blast impulse on the back face of an object.
I_F	Air blast impulse on the front face of an object.
I_i	Impulse corresponding to categories of lethal loading to reentry vehicles (i = 4, 5, 6) (Chapter 16).
I_I	Impulse from the blast intercept loading of a reentry vehicle (Chapter 16).
I_N	Net overpressure impulse on an object.
I_p	Positive phase overpressure impulse.
I_{pp}	Primary photocurrent induced in a PN junction of a transistor by transient radiation.
I_q	Dynamic pressure impulse.
I_T	Total impulse.
I_γ	Fission debris radiation intensity parameter for determination of electromagnetic signal attenuation caused by gamma rays outside of the fireball.
I'_γ	Parameter used to determine I_γ ($I_\gamma = C_\gamma I'_\gamma$, where C_γ is the debris height correction factor) (Chapter 8).
$I'_{\gamma i}$	Same as I'_γ when there are more than one debris region (i = 1, 2, 3 for bursts above 120 kilometers) (Chapter 8).

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Symbol	*Designation*
J	One-half of the plastic moment arm of a structural member.
J'	Empirical constant that relates the bubble radius of an underwater explosion at its first maximum to the weapon yield and the hydrostatic head. J' is generally taken to be 1,500 when the yield is in kilotons, and the hydrostatic head and the bubble radius are in feet.
$\bar{J}$	Electric current density.
K	Water depth and yield dependent parameter that relates the shock wave duration of an underwater explosion to the shock wave impulse and the peak shock pressure (Section IV, Chapter 2).
K	Semiconductor lifetime damage constant (Chapter 6; Section VII, Chapter 9).
K	The bulk modulus (modulus of volume elasticity) (Section V, Chapter 9).
K	Parameter used in analysis of structural damage to belowground structures (see Table 11-10) (Section II, Chapter 11).
K_g	Energy-dependent free-charge-carrier-generation constant for semiconductors (Section VII, Chapter 9).
K_H	Factor that accounts for the relative size of horizontal tails in the vulnerability analysis of aircraft (Chapter 13).
K_o	Ratio of horizontal to vertical soil pressures (Section II, Chapter 11).
$K.E.$	Kinetic energy.
$K(t)$	Semiconductor time dependent damage constant after a fast burst of nuclear radiation (Section VII, Chapter 9).
$K(\infty)$	Steady-state value of a semiconductor damage constant (Section VII, Chapter 9).
L	Length of a row crater formed by simultaneous or near simultaneous explosions (Section II, Chapter 2).
L	Length of the peak wave formed by an underwater explosion (Section IV, Chapter 2).
L	Thickness of a layer of material exposed to thermal radiation (Section III, Chapter 9).
L	Diffusion length for minority carriers on the side of a transistor junction with the longer diffusion length (Section VII, Chapter 9).

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Symbol	*Designation*
L	Span length of a buried structure (Section II, Chapter 11).
L	Preblast value of lift of an aircraft in flight (Chapter 13).
L_{down}	Length of a tube fireball measured from the burst point down the magnetic field lines (see Figure 8-16, Chapter 8).
L_n	Diffusion length in the N region of a transistor (Section VII, Chapter 9).
L_p	Diffusion length in the P region of a transistor (Section VII, Chapter 9).
L_{up}	Length of a tube fireball measured from the burst point up the magnetic field lines (see Figure 8-16, Chapter 8).
LD	Lead distance. The distance, parallel to the line of flight of a reentry vehicle (RV), between the RV and a line perpendicular to the line of flight through the burst center (see Figure 16-23, Chapter 16).
LOE	Locus of escape. The surface of a volume around a burst outside of which a reentry vehicle will not intercept the blast wave (see Figures 16-37 and 16-38, Chapter 16).
LR	Lethal ratio. A parameter dependent on yield and aircraft class that is used in determination of the vulnerability of airplanes in flight to the gust effects of the air blast wave.
L'	A parameter that determines L_{down} for bursts between 85 and 120 kilometers under certain circumstances (see Problem 8-2, Chapter 8).
L'_a	A parameter used in the determination of the absorption of electromagnetic signals propagating through a fireball at altitudes below 60 kilometers and times greater than 300 seconds after burst (Chapter 8).
M	Mass of a neutron (Chapter 5).
M	Mach number. The ratio of the velocity of an object to the ambient speed of sound (Chapters 13 and 16).
M	The dynamic constrained modulus of deformation of a medium sustaining a stress (Chapter 11).
M_p	Total capacity of a structural member under pure bending (Chapter 11).
N	Total number of photons emitted by a source per unit time (Chapter 4).
N	Generic symbol for aircraft load factor. Used for critical load factor for failure in determining intercept time sure-safe and sure-kill envelopes and the maneuver normal load factor in determining burst-time gust effect envelopes (Chapter 13).

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Symbol	*Designation*
N^+	Up-loading aircraft limit load factor (Chapter 13).
N^-	Down-loading aircraft limit load factor (Chapter 13).
N_e	Density of free electrons at a point of interest.
N_o	Total number of neutrons emitted by a source (e.g., total number of neutrons emitted during a nuclear explosion).
N_{oi}	Total number of neutrons of energy i emitted by a source.
N_β	Beta radiation intensity parameter used in determining the ion-pair production rate and electron density caused by fission product beta particles.
$N_{\beta i}$	Same as N_β; used when there are more than one debris region (i = 1, 2, 3).
N-type	See Glossary.
OD	Offset distance. The distance measured perpendicular to the line of flight of a reentry vehicle (RV) between the RV and a line parallel to the line of flight that passes through the burst center (see Figure 16-23, Chapter 16).
P	Ambient air pressure at the altitude of interest, except as noted below.
P	Radiant power (Chapter 3).
P	Pressure induced in a material by internally deposited energy (Section V, Chapter 9).
P	A parameter used in vulnerability evaluation or design of shallow buried arches (Section II, Chapter 11).
P_b	Local pressure at some desired point on a hypersonic reentry vehicle (Chapter 16).
P_f	Free stream ambient pressure around a hypersonic reentry vehicle (Chapter 16).
P_f	Probability of failure of a system or structure (Appendix C).
P_{fn}	Probability of failure of a component of a system (Appendix C).
P_{GAS}	Local pressure within a fireball (Chapter 16).
P_{max}	Radiant power at the time of the final maximum of the thermal pulse.
P_{min}	Radiant power at the time of the principal minimum of the thermal pulse.

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Symbol	*Designation*
P_o	Asymptote corresponding to the value of static pressure loading necessary to produce a specified damage level to a reentry vehicle (Chapter 16; otherwise P_o represents ambient sea level atmospheric pressure – see introductory paragraphs to this appendix).
P_s	Absolute pressure behind the shock front in air (Appendix A).
P_s	Probability of survival of a system (Appendix C).
P_u	Total capacity of a buried structure under pure thrust (Section II, Chapter 11).
P_{WALL}	Wall pressure induced by mass removal blowoff during transit of a reentry vehicle through a fireball (Chapter 16).
P_y	Uniform static pressure necessary to cause material yielding in a shell wall (Chapter 16).
$Pe(\theta)$	Probability of exposure of a point on a forest floor by a point source of thermal radiation (Chapter 15).
Pr	Prandtl number. A dimensionless quantity which is equal to the specific heat at constant pressure times the viscosity divided by the thermal conductivity. Its significance is momentum diffusivity (thermal diffusivity) (Section IV, Chapter 9).
P-type	See Glossary.
Q	Radiant exposure, i.e., thermal energy incident per unit area (generally expressed as cal/cm^2).
Q_a	Thermal energy absorbed per unit area.
Q_c	Critical heat; thermal energy per unit area required to produce a specified effect.
Q_o	Radiant exposure required to ignite dry fuels.
Q_r	Radiative heat loss from a material.
Q_{ascent}	Heat load on a reentry vehicle during ascent.
Q_{cone}	Total heat load on the cone of a reentry vehicle.
$Q_{radiation}$	Thermal radiation heating of a reentry vehicle from a nuclear burst.
$Q_{reentry}$	Normal heating of a reentry vehicle during reentry.
R	Slant range, except as noted below (generally measured from the burst to the point of interest).

Symbol	*Designation*
R	Reentry vehicle nose radius (Chapter 16).
R	Universal gas constant (Appendix A).
R_a	Radius of the apparent crater (Chapter 2).
R_a'	Critical range that determines the sure-safe or sure-kill distance from a burst above an aircraft (Chapter 13).
$R_{a\ell}$	Radius of the apparent crater lip crest.
R_{av}	Radius of a volume, centered on an aircraft, that determines the sure-safe or sure-kill locations of bursts for thermal radiation damage (Chapter 13).
R_b	Critical range that determines the sure-safe or sure-kill distance from a burst below an aircraft (Chapter 13).
R_d	Radius of the debris region from air bursts.
R_e	Radius of the outer boundary of the continuous ejecta from a crater (Chapter 2).
R_{eq}	Magnetic equilibrium radius of the fireball for high altitude bursts (Chapter 8).
R_f	Radius of the visible fireball (Chapter 3).
R_{fb}	Fireball radius for communications interference calculations (Chapter 8).
R_{inner}	Inner radius of the debris once it becomes a toroid (Chapter 8).
R_m	Maximum range of missiles thrown from a crater of a surface or near-surface burst (Chapter 2).
R_{min}	Radius of the fireball at the time of the principal minimum of thermal radiation.
R_{MR}	Radius of the main rotor blade of a helicopter (Chapter 13).
R_o	Initial fireball radius (Chapter 8).
R_s	Radius of the base surge from a water surface or subsurface burst (Chapter 2).
R_s	Critical range that determines the sure-safe or sure-kill distance from a burst at the side of an aircraft (Chapter 13).
R_{tube}	Radius of the fireball tube, measured perpendicular to the magnetic field lines, from a high altitude burst once the fireball (debris) is aligned with the geomagnetic field.
RB	Radius from the burst center to a reentry vehicle at the time of intercept of the vehicle by the blast wave (Chapter 16).

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Symbol	*Designation*
RD	Slant range from a burst to a reentry vehicle at the time of the explosion (Chapter 16).
Re	Reynolds number. A dimensionless quantity equal to the inertia force of an object divided by the viscous force on the object.
RS	Scaled radius from the burst center to a reentry vehicle at the time of intercept of the vehicle by the blast wave (RB scaled to 1 kt).
S	Clearing distance; the shortest distance from the stagnation point of a blast wave interacting with a structure to a clear edge on the structure (Chapter 11).
S	Area of the wing or horizontal tail of an aircraft including the extensions of the leading and trailing edges to the aircraft centerline (Chapter 13).
S_d	Altitude scaling factor used to scale distance for various blast parameters to different ambient air pressures.
S_p	Altitude scaling factor used to scale overpressure or dynamic pressure to different ambient air pressures.
S_t	Altitude scaling factor used to scale the time of arrival of the air blast wave to different ambient air pressures.
S_w	Total area of the wings of a helicopter (if there are wings). Measured by the extension of the leading and trailing edges of both wings to the aircraft centerline.
S^*	The shear modulus of a material (Section V, Chapter 9).
SGZ	Surface ground zero. Used mainly in measuring crater dimensions from surface or near surface bursts. That point on the earth which is directly below, directly above or at the point of the explosion (see *GZ, SZ*).
SH	Semi-height of a pancake shaped fireball. This is the shape that the fireball formed by bursts below 85 kilometers ultimately assumes (Chapter 8).
SZ	Surface zero. Used mainly for water surface or subsurface bursts. That point on the earth that is directly below, directly above, or at the point of the explosion (see *GZ, SGZ*).
T	Transmittance factor. That fraction of thermal energy emitted from a nuclear explosion that reaches a target (Chapter 3).
T	Absolute temperature (Section I, Chapter 2, Chapter 4, Appendix A).
T	Period of vibration of a structure (Chapter 11).

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Symbol	*Designation*
T	Duration of a shock wave in water (Section IV, Chapter 2).
T_c	Critical temperature of aircraft skin panels. For sure-safe conditions, it is the temperature at which the modulus of elasticity of the thinnest structural skin on the fuselage is reduced by 20 percent. For sure-kill conditions, it is the temperature at which the thickest structural skin on the fuselage will melt.
T_d	Transmission coefficient for the direct flux of thermal energy.
T_e	Effective radiating temperature (Chapter 4).
T_e	Equilibrium temperature of the skin of an aircraft prior to exposure to thermal radiation (Chapter 13).
T_m	Melting temperature of a material of interest (Section IV, Chapter 9).
T_o	Absolute temperature of the air surrounding an object of interest that is exposed to thermal radiation (Section IV, Chapter 9). (Otherwise, T_o refers to ambient air temperature at sea level – see introductory remarks to this appendix).
T_r	Strain or velocity rise time for direct-transmitted ground shock from a buried explosion.
T_s	Surface temperature of the radiating volume of a nuclear explosion.
T_W	Absolute temperature at the outer surface of the ablator of a reentry vehicle (Chapter 16).
U	Velocity of propagation of the shock front.
V	Maximum value of ground motion velocity (Chapter 2).
V	Visual range (Chapter 3).
V	Velocity of an aircraft or missile (Chapters 9, 13, and 16).
V	Specific volume of undisturbed air (Appendix A).
V_a	Volume of the apparent crater produced by a nuclear explosion.
V_o	Initial spray velocity from an underwater explosion.
V_E	Reentry velocity (Chapter 16).
W	Weapon yield, except as noted below (generally in kilotons, but, where specified, may be in megatons).
W	Reentry vehicle mass (Chapter 16).

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Symbol	*Designation*
W'_{coll}	Work performed by the air blast overpressure to produce kinetic energy in the air.
W'_{comp}	Work done by the ambient pressure in compressing the air during passage of a blast wave.
W'_{eff}	Effective blast yield (Chapter 2).
W'_{eff}	Effective thermal yield (Chapter 3).
W'_F	That portion of the weapon yield that is derived from fission.
W''_F	Debris region fission yield (Chapter 8).
W'_{HE}	Weight of a high explosive charge (given in equivalent pounds of TNT).
W'_T	Thermal energy radiated by a nuclear explosion.
W'_{total}	Total work done on a unit mass of air as it is engulfed by the blast wave.
W'_x	The X-ray yield of a weapon.
W_γ	The gamma-ray yield of a weapon.
X	Fraction of the debris from an explosion above 120 kilometers that goes to debris region 3 (the conjugate region) (Chapter 8).
X	Arching factor for a roof of a buried structure (Chapter 11).
X	Length, measured along the center line, from the nose tip to a point on a reentry vehicle body (Chapter 16).
X_d	Closest point of approach of a communication system ray path to the center of the debris region. Used in calculation of absorption by the region of space that is ionized by gamma rays emitted by the debris.
X_o	Distance (measured head-on or tail-on) between a reentry vehicle and a nuclear burst at the time of the explosion (Chapter 16).
Y_o	Yield strength of a material (compressive yield strength if that is different from its yield strength in simple tension) (Section V, Chapter 9).
Z	Hydrostatic head for an underwater burst (taken to be equal to the depth of burst plus 33 feet) (Chapter 2).
Z	Atomic number of an element (Chapter 4, Section V, Chapter 9).
a	Incremental path absorption of an electromagnetic signal (absorption per unit distance traveled) (Chapter 8).

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Symbol	*Designation*
a	Acceleration of a buried structure resulting from ground shock (Chapter 11).
a_r	Peak acceleration in the radial direction from direct transmitted ground shock (Section III, Chapter 2).
a_s	Maximum acceleration of the ground at the surface resulting from air-induced ground shock.
a_n	Peak horizontal component of acceleration at a point below the earth's surface resulting from ground shock (Section III, Chapter 2).
a_y	Peak vertical component of acceleration at a point below the earth's surface resulting from ground shock (Section III, Chapter 2).
b	Thickness of a metal plate exposed to thermal radiation and air blast (Section IV, Chapter 9).
b	Span, tip to tip, of the wing or horizontal tail of an aircraft (Chapter 13).
b	Median of a lognormal variable (Appendix C).
b_L	Clear span of the long side of a rectangular buried structure (Section II, Chapter 11).
b_s	Clear span of the short side of a rectangular buried structure (Section II, Chapter 11).
c	Ambient speed of sound in air (Chapter 2, Chapter 13, Appendix A).
c	Velocity of light (Chapter 4).
c	Seismic velocity of structural material (Chapter 11).
c_E	Elastic velocity of a shock wave traveling through a material (Section V, Chapter 9).
c_m	Seismic velocity of a particular structural type (Chapter 11).
c_{MR}	Helicopter main rotor blade chord length (Chapter 13).
c_o	Bulk sound speed in a material (Section V, Chapter 9, otherwise ambient speed of sound in air at sea level).
c_p	Local pressure coefficient for aerodynamic loading on hypersonic reentry vehicles (Chapter 16).
c_p	Seismic velocity of a medium in which a structure is buried (Chapter 11).

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Symbol	Designation
c_r	Wing/horizontal tail root chord, i.e., the length along the fuselage centerline subtended by extensions of the leading and trailing edges (Chapter 13).
c_t	Wing/horizontal tail tip chord, i.e., the length along the fuselage centerline subtended by the wing/horizontal tail tip (Chapter 13).
d	Horizontal distance from ground zero, or surface zero for underwater bursts, except as noted below.
d	Distance at which the case shock arrives at the hydrodynamic shock front, which marks the beginning of a scalable shock wave (Section I, Chapter 2).
d	Horizontal distance between two points at different altitudes (Chapter 4).
d	Displacement of a buried structure by ground shock (Chapter 11).
d	Fuselage depth at the intersection of the leading edge of the vertical tail with the fuselage (Chapter 13).
d_{ac}	Depth of the apparent crater from an underwater burst (Section IV, Chapter 2).
d_b	Depth of burst.
d_r	Maximum radial displacement of the earth caused by ground shock (Chapter 2).
d_r	Damage reduction distance; the amount by which the horizontal distance from ground zero at which a specified level of damage to a surface target is less for a subsurface burst than for a surface burst (Chapter 11).
d_s	Differential displacement of the earth at the surface caused by ground shock (Chapter 2).
d_{se}	Differential transient elastic displacement of the earth at the surface caused by ground shock (Chapter 2).
d_{sp}	Permanent displacement of the earth at the surface caused by ground shock (Chapter 2).
d_w	Depth of the water where an underwater explosion occurs.
d_x	Horizontal displacement of the earth at a point below the surface caused by ground shock (Chapter 2).
d_y	Vertical displacement of the earth at a depth "y" caused by ground shock (Chapter 2).
d_{ye}	Differential elastic transient vertical displacement of the earth at a depth "y" caused by ground shock (Chapter 2).

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Symbol	*Designation*
d_{yp}	Permanent vertical displacement of the earth at a depth "y" caused by ground shock (Chapter 2).
d_2	Depth of the bubble from an underwater burst at the second maximum radius (Chapter 2).
d_3	Depth of the bubble from an underwater burst at the third maximum radius (Chapter 2).
e_c	Compton electron (Chapter 7).
e_o	Hydrodynamic yield. Used primarily for underwater high explosive bursts (Chapter 2).
f	Natural frequency of an oscillator (Section III, Chapter 2).
f	Retardation factor of the spray from an underwater burst (Section IV, Chapter 2).
f	Thermal partition of the total yield (Chapter 3 and Chapter 13).
f	Fraction of total weapon energy emitted as prompt gamma rays (Chapter 5).
f	Frequency of an electromagnetic signal in megahertz (Chapter 8).
f_h	Factor to correct the fireball height as a function of time when the maximum altitude to which the fireball rises is greater than 200 kilometers (Chapter 8).
f_o	Factor to correct the debris offset when the maximum fireball rise exceeds 200 kilometers (Chapter 8).
f_y	Yield strength of reinforcement in an underground concrete structure (Chapter 11).
f_c'	Strength of the concrete in an underground structure (Chapter 11).
h	Height of burst, except as noted below.
h	Maximum spray dome height from an underwater burst (Section IV, Chapter 2).
h	Planck's constant (6.625×10^{-27} erg-sec) (Chapter 4, Section V, Chapter 9).
h	Relative humidity (Section III, Chapter 9).
h	Height of a buried arch type structure (Section II, Chapter 11).
h	Aircraft flight altitude (Chapter 13).
h	Altitude along a reentry vehicle flight path (Section II, Chapter 16).

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Symbol	*Designation*
h_b	Altitude of the base of the fireball tube once the fireball from a high altitude burst forms a tube along the geomagnetic field lines.(Chapter 8 – see Figure 8-16).
h_c	Height of the visible base surge cloud from an underwater explosion (Section IV, Chapter 2).
h_c	Reentry vehicle or defensive missile ablator thickness (Chapter 16).
h_{cv}	Convective heat loss for turbulent flow (Section IV, Chapter 9).
h_d	Altitude of the weapon debris (Chapter 8).
h_{di}	Same as h_d when there are more than one debris region (i = 1,2,3 for bursts above 120 kilometers) (Chapter 8).
h_{fb}	Altitude of the fireball (Chapter 8).
h_ℓ	Height of the apparent crater lip from an underwater burst (Section IV, Chapter 2).
h_m	Maximum altitude to which the fireball rises (Chapter 8).
h_{mi}	Maximum altitude to which the weapon debris rises when there are more than one debris region (i = 1,2,3 for bursts above 120 kilometers) (Chapter 8).
h_N	Normalizing factor to obtain fireball height at times before the fireball reaches its maximum altitude (Chapter 8).
h_o	Detonation altitude – used as the starting altitude to determine the location of the fireball at various times after burst (Chapter 8).
h_r	Distance that a fireball will rise above the detonation point (Chapter 8).
h_1, h_2	Altitudes of two points of interest in the determination of the mass integral of air between them (Chapters 4 and 5).
h'_{cv}	Convective heat loss for laminar flow (Section IV, Chapter 9).
k	Linear spring constant (Section III, Chapter 2).
k	Boltzmann constant (1.38×10^{-16} erg/°K) (Chapter 4).
k	Thermal conductivity (Section III, Chapter 9).
k	Factor for the calculation of the aerodynamic coefficient of vertical tails of aircraft (function of the vertical tail span, and the fuselage depth) (Chapter 13).

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Symbol	*Designation*
m	Mass attached to a linear spring (Section III, Chapter 2).
m	Mass of a body into which energy has been deposited (Section V, Chapter 9).
m	Mean value of the intensity of motion used in the calculation of damage probabilities (Appendix C).
m_i	Median value of input motion used in the calculation of damage probabilities (Appendix C).
m_o	Rest mass of an electron (Chapter 4).
m_v	Median value of the vulnerability level of motion (Appendix C).
$\dot{m}$	Rate of mass removal from a missile ablator material (Chapter 16).
n	Number of explosive charges in a row crater (Section II, Chapter 2).
n	Period of an oscillating underwater bubble (Section IV, Chapter 2).
n	Preblast load factor on an aircraft (Chapter 13).
p_b	Pressure on the back face (face away from the burst) of an object exposed to an air blast wave (Section II, Chapter 9).
p_1	Peak value of stress applied to a buried structure (Section II, Chapter 11).
p_f	Pressure on the front face (face nearest the burst) of an object exposed to an air blast wave (Section II, Chapter 9).
p_f	Percentage of reinforcement in a reinforced concrete buried structure (Section II, Chapter 11).
p_H	Static radial soil pressure on a buried structure (Section II, Chapter 11).
p_h	Horizontal component of stress at a point below the surface in soil (Chapter 11).
p_i	Stress at the interface between two media through which a shock wave is traveling (Section III, Chapter 2).
p_m	Peak shock pressure in water (Section IV, Chapter 2).
p_r	Reflected stress at the interface between two media through which a shock wave is traveling (Section III, Chapter 2).
p_{so}	Peak side-on overpressure. Generally used to represent the overpressure at the surface of the earth in the calculation of air-induced ground shock (Section III, Chapter 2, and Section II, Chapter 11).

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Symbol	*Designation*
$(p_{so})_a$	Component of overpressure at the surface that produces thrust in a buried arch (Section II, Chapter 11).
$(p_{so})_b$	Component of overpressure at the surface that produces flexure.
p_t	Transmitted stress at the interface between two media through which a shock wave is traveling (Section III, Chapter 2).
p_v	Vertical component of stress at a point below the surface in soil (Chapter 11).
q	Peak value of the dynamic pressure of the air blast wave, except as noted below.
q	Charge of an electron (1.6×10^{-19} coulombs) (Section VI, Chapter 9).
$q(h)$	Mass integral of air above a point at altitude "h" (Chapter 4).
$q(R)$	Mass integral of air between two points separated by a slant range "R" (Chapter 4).
q_{eq}	That dynamic pressure under nonideal surface conditions from which the dynamic pressure impulse would cause a particular level of damage for a particular yield and height of burst (Chapter 14).
q_u	Ultimate bearing strength of soil (Chapter 11).
q_y	Yield resistance of a buried structure (Chapter 11).
$\dot{q}_c$	Forced convection caused by friction forces at the boundary layer around a missile that produces aerodynamic heating during flight (Chapter 16).
$\dot{q}_R$	Heating rate of a missile during traversal through a fireball (Chapter 16).
	Radius of a high temperature black body source of electromagnetic radiation emission (Chapter 4).
r	Radius of a buried dome or arch (Chapter 11).
r	Radius of turn of a maneuvering aircraft (Chapter 13).
r_{ac}	Radius of the apparent crater from an underwater explosion (Section IV, Chapter 2).
r_q	Radius of gyration of an element of a buried structure (Section II, Chapter 11).
r_n	Parameter that relates the energy of the bubble from an underwater burst to the energy of the preceding (n-1) bubble (Section IV, Chapter 2).
r_{su}	Horizontal extent of the spray dome from an underwater burst (Section IV, Chapter 2).

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Symbol	*Designation*
s	Space between charges in row of explosive charges emplaced to produce a row crater (Section II, Chapter 2).
s	Support condition for an element of a buried structure (Section II, Chapter 11, see Table 11-10).
t	Time after burst that the shock front of an air blast wave reaches a point of interest; also, the instantaneous value of time subsequent to shock front arrival (Chapter 2).
t	Time after burst (Chapter 5 and Chapter 8).
t	Aircraft skin thickness (Chapter 13).
t_a	Time of arrival of the blast wave at a point of intercept with an aircraft (Chapter 13).
t_{bky}	Time of breakaway, the time at which the shock front becomes detached from the fireball (Chapter 2 and Chapter 3).
t_c	Time of intersection of a reentry vehicle with a blast wave (see Figure 16-37) (Chapter 16).
t_{csa}	The time of case-shock arrival at the hydrodynamic shock front (Chapter 2).
t_d	Effective duration of the loading on a buried structure (Chapter 11).
t_d	Transistor switching delay time (Section VII, Chapter 9).
t_e	Thickness of the ejecta from a surface or near surface burst (Chapter 2).
t_E	Time of exit of a reentry vehicle from the blast shell (Chapter 16).
t_{EFB}	Time of exit of a reentry vehicle from the fireball (Chapter 16).
t_f	The fall time portion of the switching time of a transistor (Section VII, Chapter 9).
t_i	Effective duration of the air-induced ground shock (Section III, Chapter 2).
t_I	Time of intercept of a reentry vehicle by a blast wave (Chapter 16).
t_{max}	Time to final maximum on the fireball power-time curve.
t_{min}	Time to the principal minimum on the fireball power-time curve.
t_o	Time of detonation (used in determining the locus of escape of a reentry vehicle from the air blast – see Figure 16-37) (Chapter 16).

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Symbol	Designation
t_r	Effective velocity pulse rise time for air-induced ground shock (Section III, Chapter 2).
t_r	Time for weapon debris to reach its maximum altitude (Chapter 8).
t_r	The storage time portion of a transistor switching time (Section VII, Chapter 9).
t_s	Time after burst for computation of underwater burst phenomena (Section IV, Chapter 2).
t_s	Charge storage time for an electronic device of interest (Section VII, Chapter 9).
t_{sf}	Shock formation time (Section I, Chapter 2).
t_{sr}	Reduced time after burst for computation of underwater burst phenomena (Section IV, Chapter 2).
t_{sr}	Radiation storage time for an electronic device of interest (Section VII, Chapter 9).
t_{toroid}	Time at which the fireball forms a toroid (Chapter 8).
t_x	Time for a reentry vehicle to travel from its location at burst time to intercept with the blast wave (see Figure 16-37) (Chapter 16).
$t_{1\ max}$	Time to reach the first (traditional first – see paragraph 3-11) maximum of the fireball power-time curve.
$t_{10\%}$	Time at which the blast intercept load on a reentry vehicle decays to ten percent of its maximum value (Chapter 16).
t_{Δ}	Effective duration of the pressure pulse of an air blast wave when it is represented as a simple triangular pulse (Section I, Chapter 2).
t_p^+	Duration of the positive phase of the overpressure of an air blast wave.
t_q^+	Duration of the positive phase of the dynamic pressure of an air blast wave.
t'	Time required for the fireball to reach its equilibrium radius (applies to bursts between 85 and 120 kilometers) (Chapter 8).
u	Particle (wind) velocity behind the shock front, except as noted below.
u	Maximum relative displacement of a simple linear oscillator (mass on a spring) (Section III, Chapter 2).
u	Normalized photon energy (a dimensionless quantity) (Chapter 4).
$\dot{u}$	Velocity of a simple linear oscillator (mass on a spring) (Section III, Chapter 2).

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Symbol	*Designation*
$\dot{u}_{max}$	Maximum of $\dot{u}$.
v	Particle velocity in a particle in a soil medium that is transmitting a ground shock (Section III, Chapter 2; Section III, Chapter 11).
v	Velocity of a neutron (Chapter 5).
v_r	Radial velocity of a particle in a soil medium that is transmitting ground shock (Section III, Chapter 2).
v_s	Maximum velocity of a particle in a soil medium that is transmitting ground shock (Section III, Chapter 2).
v_x	Horizontal velocity of a particle in a soil medium that is transmitting ground shock (Section III, Chapter 2).
v_y	Vertical velocity of a particle in a soil medium that is transmitting ground shock (Section III, Chapter 2).
w	Width of the depletion layer between N and P sections of a semiconductor (Section VII, Chapter 9).
w	Component of aircraft velocity normal to the wing (Chapter 13).
w	A parameter used in characterizing the ionization caused by beta and gamma radiation from several high altitude bursts (Chapter 17).
x	Transient displacement induced by ground shock (used in the representation of ground shock induced motion by a simple oscillator) (Section III, Chapter 2).
x	Penetration distance of a beam of particles or electromagentic radiation into a material (Chapters 4 and 5).
x	Semithickness of the fireball once it has assumed a pancake shape (see Figure 8-16) (Chapter 8).
x	Spacing between members of a structure (Section III, Chapter 11).
x_s	Deflection of a system mounted in a buried structure when subjected to ground shock (Section III, Chapter 11).
$\dot{x}$	Velocity of the base of a simple oscillator used to represent ground shock induced motion (Section III, Chapter 2).
$\ddot{x}$	Acceleration of the base of a simple oscillator used to represent ground shock induced motion (Section III, Chapter 2).
y	Depth below the surface of the earth (Section III, Chapter 2).

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Symbol	*Designation*
y	Coordinate of motion of the mass of a simple oscillator used to represent ground shock induced motion (Section III, Chapter 2).
$\dot{y}$	Velocity of the mass of a simple oscillator used to represent ground shock induced motion (Section III, Chapter 2).
$\ddot{y}$	Acceleration of the mass of a simple oscillator used to represent ground shock induced motion (Section III, Chapter 2).
z	Depth from the ground surface at which the radial load on a buried vertical cylinder is desired (Section II, Chapter 11).
Γ	Parameter used in the analysis of damage to buried structures. The parameter is defined by structural type and dimensions in Table 11-10.
Δ_d	Distance by which the weapon debris is offset from ground zero toward the nearest magnetic pole (Chapter 8).
Δ_β	Distance by which the beta particle absorption region is offset from ground zero (or from the conjugate ground zero, see Figure 8-53) toward the nearest magnetic pole (Chapter 8).
$\Delta\beta_i$ $(i = 1,2,3)$	Distances by which the beta particle absorption regions are offset from ground zero (or from the conjugate ground zero) when there are three debris regions (see Figure 8-18) (Chapter 8).
ΔE	Energy density deposited by X-rays within a given volume of air (Chapters 2 and 3).
ΔE	Change of internal energy per unit mass of an ideal gas when the gas is heated at constant volume (Appendix A).
Δh	Absolute value of the difference in burst altitude and target altitude (targets above the surface) (Chapter 3).
ΔL	Incremental lift on an aircraft resulting from the air blast wave (Chapter 13).
Δp	Peak overpressure of an air blast wave.
$\Delta p(t)$	Instantaneous value of the overpressure as a blast wave passes a point of interest.
Δp_{eq}	Equivalent overpressure under near-ideal surface conditions at which the dynamic pressure impulse for a particular yield and height of burst would cause a particular level of damage (Chapter 14).
Δp_r	Peak reflected overpressure.

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Symbol	*Designation*
ΔR	Change in fireball radius at times later than seven minutes after burst (Chapter 8).
ΔT	Critical temperature rise of an aircraft skin for sure-safe or sure-kill conditions (Chapter 13).
Δt_{FB}	Traversal time of a missile through a fireball (Chapter 16).
Δt_{ILP}	Missile intercept time load constant (equals the time of intercept by a blast wave minus the time at which the blast load decreases to ten percent of the intercept value) (Chapter 16).
Δt_t	Total time for a missile to traverse through a blast wave shell (Chapter 16).
ΔZ_i	Distance of upward migration of an underwater bubble during the ith period (i = 1,2,3) (Section IV, Chapter 2).
$\Lambda_{c/2}$	Sweepback angle of the mid-chord line of an aircraft wing or horizontal tail (Chapter 13).
Λ_{LE}	Sweepback angle of the leading edge of an aircraft wing or horizontal tail (Chapter 13).
Φ	Angle between the direction of propagation of a shock wave and the line of steepest ascent or descent of a slope that the shock wave encounters (Chapter 2).
Φ	Particle, photon, or energy flux (Chapters 4 and 5).
Φ	Angular change in an aircraft's flight path between burst time and blast intercept time (Chapter 13).
Φ_s	X-ray energy flux at the source; the total power emitted per unit area of the source per unit time (Chapter 4).
$\Phi_{\gamma p}$	Prompt gamma output energy rate (Chapter 5).
Ψ	Energy density radiated by a black body between wavelengths λ and $\lambda + d\lambda$ (Planck spectrum) (Chapter 4).
Ω_{MR}	Angular velocity of the main rotor of a helicopter (Chapter 13).
α	Coefficient for determination of attenuation of ground shock with depth (see note on page 2-180 for description of differences in attenuation coefficients in Section III, Chapter 2 and Section II, Chapter 11) (Section III, Chapter 2).
α	Thermal diffusivity of a material (Section III, Chapter 9).

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Symbol	*Designation*
α	Parameter used to determine the reciprocal of the ground shock depth attenuation coefficient (see Figure 11-29; not equal to depth attenuation of Chapter 2, see note on page 2-180) (Chapter 11).
α	Thermal absorptivity coefficient of an aircraft surface (Chapter 13).
α	Reentry vehicle angle-of-attack; the angle between the longitudinal axis of the vehicle and the relative wind vector (wind from either an air blast wave or normal atmospheric forces) (Chapter 16).
α_e	Coefficient of thermal expansion of a material (Section IV, Chapter 9).
β	Elevation angle of electromagnetic signal propagation (Chapter 8).
β	Reciprocal of the ground shock attenuation coefficient (not equivalent to $1/\alpha$ of Section III, Chapter 2; see note on page 2-180) (Section II, Chapter 11).
β	Radiative heat blocking function of the surface of a reentry vehicle (Chapter 16).
β	Circumferential angle on the structure of a reentry vehicle measured from the windward ray of intercept with a blast wave (Chapter 16).
β	Reentry vehicle ballistic coefficient (Chapter 16).
β	Standard deviation of the logarithm of a variate in a logarithmic normal distribution (Appendix C).
β_i	Standard deviation of the logarithm of the input function (Appendix C).
β_v	Standard deviation of the logarithm of the vulnerability function (Appendix C).
β_r	Rotational angle about the axis of a reentry vehicle (Chapter 16).
β_o	Gain of a transistor prior to irradiation (Section VII, Chapter 9).
$\beta_\varphi(t)$	Gain of a transistor as a function of time after irradiation (Section VII, Chapter 9).
$\beta_\varphi(\infty)$	Steady state value of the gain of a transistor that is reached after irradiation and annealing (Section VII, Chapter 9).
γ	Ratio of the specific heat of air at constant pressure to the specific heat of air at constant volume at moderate temperatures and pressures; for strong shocks, γ simply becomes a constant in the energy equation of an ideal gas (see paragraph A-2, Appendix A) (Section I, Chapter 2; Chapter 16; and Appendix A).
γ	Unit weight of a medium that is transmitting ground shock (Section III, Chapter 2).

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Symbol	*Designation*
γ	Parameter used in determining the effective shock pulse duration on buried structures (Section III, Chapter 11).
γ_E	Terminal flight path angle of a reentry vehicle (Chapter 16).
γ'	Effective shock pulse duration on buried structures (Section III, Chapter 11).
δ	Underwater burst spray dome angle (see sketch in Problem 2-32) (Section IV, Chapter 2).
δ	Characteristic thermal thickness of a material. If a thick slab of material is exposed to a rectangular thermal pulse, the temperature at the surface would be about the same as would be produced by uniformly distributing the absorbed thermal energy in a slab of thickness δ, and the peak temperature rise at depth δ in the thick slab is about half as great as the peak temperature rise at the surface (Section III, Chapter 9).
δ	Parameter used in analysis of vulnerability of buried structures (defined in Table 11-10) (Section II, Chapter 11).
δ	Semivertex angle of a reentry vehicle (Chapter 16).
ϵ	Strain; the deformation resulting from stress measured by the ratio of the change to the total dimension in which the change occurred (Section III, Chapter 2; Section IV, Chapter 9; Chapter 16).
ϵ	Thermal efficiency; the fraction of energy absorbed by air that is reradiated (Chapter 3).
ϵ	Internal energy per unit volume (Section V, Chapter 9).
ϵ	Emissivity of a heated system (Section IV, Chapter 9).
η	Ratio of the time of arrival of the blast wave to the time to final thermal maximum (Section IV, Chapter 9).
η	Ratio of the density of a material at pressures above ambient to the density of the same material at ambient pressures (Section V, Chapter 9).
η	Parameter used in the calculation of blast intercept time envelopes for helicopters (Chapter 13).
θ	Effective slope angle for the interaction of a blast wave with a rising or falling slope (θ is equal to the actual slope angle, θ_s, if the direction of propagation of the blast wave is perpendicular to the foot of the slope) (Section I, Chapter 2).

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Symbol	*Designation*
θ	Time constant of an underwater shock wave (Section IV, Chapter 2).
θ	Angle that the direction of propagation of a Compton scattered photon makes with direction of the original photon (Chapter 4).
θ	Angle of incidence of an electromagnetic signal ray path with an imaginary shell 65 kilometers above the surface of the earth (Chapter 8).
θ	Angle formed by two lines through the burst point – one line parallel to a reentry vehicle's flight path and the other through the reentry vehicle at burst time (see Figure 16-23) (Chapter 16).
θ_{cone}	Angle from the longitudinal axis of a cone shaped reentry vehicle to the edge of the vehicle (Chapter 16).
θ_d	Angle between a horizontal plane through the debris center and the geomagnetic field lines that pass through the debris (Chapter 8).
θ_i	Angle of incidence of a blast wave as it strikes a reflecting surface; the angle that the *shock front* (not the direction of propagation of the blast wave) makes with the surface (see footnote on page 2-38) (Section II, Chapter 2).
θ_s	Actual angle of a rising or falling slope that a blast wave encounters – measured perpendicular to the foot of the slope.
κ	Mass attenuation coefficient (Chapter 4 and 5).
λ	Photon wavelength (Chapter 4).
λ	Taper ratio of an aircraft wing, horizontal tail or vertical tail (length along the fuselage centerline subtended by the wing/tail tip divided by the length along the fuselage centerline subtended by the leading and trailing edges) (Chapter 13).
λ'	Wavelength of a scattered photon (Chapter 4).
μ	Linear attenuation coefficient; the probability of interaction per unit distance traveled by particulate or electromagnetic radiation, except as noted below.
μ	Viscosity of air (Section IV, Chapter 9).
μ_a	Linear absorption coefficient; the probability, per unit distance traveled, of an interaction in which energy is absorbed by the medium being traversed (in this manual the symbol is only used for photon (X-ray or gamma ray) interactions) $(\mu_a + \mu_s = \mu)$.
μ_{ce}	Rayleigh scattering (coherent elastic scattering) linear attenuation coefficient (for photons $\mu_{ce} + \mu_{ie} = \mu_s$).

Symbol	*Designation*
μ_{ie}	Compton elastic (incoherent elastic scattering) linear attenuation coefficient (for photons $\mu_{ce} + \mu_{ie} = \mu_s$).
μ_{is}	Compton inelastic scattering linear attenuation coefficient (for photons $\mu_{is} + \mu_p = \mu_a$).
μ_p	Photoelectric linear attenuation coefficient (for photons $\mu_p + \mu_{is} = \mu_a$).
μ_s	Linear scattering coefficient; the probability of interaction, per unit distance traveled, that removes radiation from the direct beam (in this manual the symbol is only used for photon (X-ray or gamma ray) interactions) ($\mu_a + \mu_a = \mu$).
ν	Poisson's ratio (Section III, Chapter 2; Section II, Chapter 11).
ν	Photon frequency (Chapter 4; Section V, Chapter 9).
ν	Electron collision frequency (Chapter 8).
ξ	Shock strength ($\xi = \Delta p/P + 1$, where Δp is the peak overpressure and P is the absolute ambient pressure).
ρ	Mass density.
ρ_c	Mass density of reentry vehicle ablative cover materials (Chapter 16).
ρ_e	Density of electrons in a medium through which X-rays are penetrating (Chapter 4).
ρ_{GAS}	Local density within a fireball (Chapter 16).
ρ_m	Weight density of the material of the skin of an aircraft (Chapter 13).
ρ_o	Normal density of a material prior to absorption of energy (Section V, Chapter 9); otherwise, mass density of air at ambient sea level conditions.
ρ_s	Mass density of the shell of a reentry vehicle (Chapter 16) otherwise, mass density of air behind a shock front.
ρ_w	Density of water in which an underwater explosion takes place (Section IV, Chapter 2).
ρ_1	Density of shocked air after reflection from a solid barrier (Appendix A).
$\bar{\rho}$	Relative air density ($\bar{\rho} = \rho/\rho_o$, where ρ is the air density at the altitude of interest and ρ_o is the air density at sea level).
σ	Stefan-Boltzmann constant (Chapter 4; Section IV, Chapter 9).

Symbol	*Designation*
σ	Cross section for a given nuclear reaction (see Glossary for definition of cross section) (Chapters 4 and 5).
σ	Conductivity (σ_{air}, air conductivity; σ_g, ground conductivity) (Chapter 7).
σ	Stress; the force per unit area tending to produce deformation in a body (Section IV, Chapter 9; Section II, Chapter 11; Section II, Chapter 16).
σ	Standard deviation for damage probability calculations (Appendix C).
σ_A	Allowable stress on a reentry vehicle (Chapter 16).
σ_D	Stress developed on a reentry vehicle for prescribed flight conditions and loads (Chapter 16).
σ_{yc}	Yield stress of a reentry vehicle ablative cover material (Chapter 16).
σ_{ys}	Yield stress of a reentry vehicle shell (Chapter 16).
$\tau(h)$	Effective optical height of the burst height for specifying thermal transmittance (Chapter 3).
τ	Emission time of prompt gamma rays (Section I, Chapter 5).
τ	Semiconductor minority-carrier lifetime (Chapter 6).
τ_{eff}	Effective semiconductor lifetime (Section VII, Chapter 9).
τ_{FB}	Scaled time of fireball traversal by a reentry vehicle (Chapter 16).
τ_I	Scaled time of intercept of a reentry vehicle by a blast wave (Chapter 16).
τ_{ILP}	Scaled duration of the intercept load of a blast wave on a reentry vehicle (Chapter 16).
τ_o	Pre-irradiation semiconductor minority-carrier lifetime (Chapter 6; Section VII, Chapter 9).
τ_o	Characteristic thermal response time that relates the response of a material to the thermal pulse (Section III, Chapter 9).
τ_{surf}	Semiconductor surface lifetime (Section VII, Chapter 9).
τ_t	Scaled time of blast traversal by a reentry vehicle (Chapter 16).
τ_φ	Semiconductor minority-carrier lifetime at fluence φ (Chapter 6; Section VII, Chapter 9).

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Symbol	*Designation*
φ	Total energy, particle, or photon fluence at a point of interest, except as noted below.
φ	Angle formed by the geomagnetic field line and a vertical line through the main debris location once a tube fireball has been formed from bursts between 85 and 120 kilometers. It is the magnetic dip angle at the location of the debris (see Figure 8-16) (Chapter 8).
φ	Angle of internal friction for nongranular soils (Section II, Chapter 11).
φ	Angle between a line through the burst point and a reentry vehicle at burst time and a line between the burst point and the reentry vehicle at blast intercept time (see Figure 16-23) (Chapter 16).
φ_{dir}	Energy, particle, or photon fluence that arrives in a direct line from the source to a point of interest, i.e., the total fluence minus the scattered fluence.
φ_o	Incident X-ray fluence that arrives normal (perpendicular) to a surface of interest (Section V, Chapter 9).
ψ	Ratio of impedances of two media where a ground shock wave is crossing the interface between the media (Section III, Chapter 2).
ψ	Parameter used in analysis of damage to underground structures. ψ depends on structural type, dimensions and seismic velocity. Relations are given in Table 11-10 (Section II, Chapter 11).
ψ	Convective heat blocking function that helps determine the fraction of free field heating rate that exists at an ablator surface (Chapter 16).
ω	Circular frequency of a simple oscillator (Section III, Chapter 2).
ω	Electromagnetic wave frequency in radians per second (Chapter 8).

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